HAND BOOK
OF
MINERALOGY

AJOY KUMAR SEN, M. Sc., F. G. M. S., F. G. S.

Department of Geology,
Asutosh College, Calcutta-700 026
&
Part-time Lecturer in Geology,
College of Ceramic Technology, Calcutta-700 010.

Director,
Institute of Tourism, Calcutta. Calcutta-700 029,
&
Former Part-time Lecturer,
Regional Orientation Centre,
National Service Scheme,
University of Calcutta,
Calcutta-700 073.

MODERN BOOK AGENCY PRIVATE LIMITED
10, Bankim Chatterjee Street
Calcutta-700 073

Published by:
Sri R. N. Bhattacharyya, B.A.
for Modern Book Agency Private Ltd.,
10, Bankim Chatterjee Street,
Calcutta-700 073.

First Published—1948

Printed by:
Parimal Kumar Basu
Basusree Press
80/6, Grey Street,
Calcutta-700 006.

PREFACE

This book has particularly been written to cover syllabus on Mineralogy for the students of under graduate classes of different Indian Universities. There are some excellent books of this type by English and American authors, but these do not conform to curricula prevalent in our country; the need for mineralogy books, geared to the needs of Indian students is, therefore, imperative.

The author express his thanks and gratitude to Prof. Bikas Chandra Pal, Prof. Sudhindra Kumar Banerjee, Prof. Abdul Matin and Prof. Debdas Roy of Asutosh College, Calcutta and Prof. Tarakeswar Mitra and Prof. Ashok Banerjee of Presidency College, calcutta. Sri Arun Kumar Sen of Central Library, University of Calcutta for the help rendered in the reading of manuscript and proof corrections. The author is very much grateful to his Publisher, Modern Book Agency Pvt Ltd. and particularly to Sri Rabindra Narayan Bhattacharyya for the constant help and co-operation. The author is also very much grateful to his friend Sri Anuj Ganguly and Sri Nemai Halder of Asutosh College for typing the manuscript.

Department of Geology, Asutosh College, Calcutta-700 026.

A. K. S.

CONTENTS

CHAPTER I

INTRODUCTION

Mineralogy is a branch of Geological Sciences, concerning with the study of minerals. Minerals are bodies produced by the processes of inorganic nature and are constituents of rocks which form the crust of the earth. A *mineral* is a homogenous substance, having a definite chemical composition and a definite atomic structure and produced by the process of inorganic nature. Diamond, Chalcopyrite, Hematite, Quartz, Calcite are examples of minerals. Ice, water and mercury are also regarded as mineral.

Minerals and rocks are not merely objects of human curiosity. They are, on the other hand, the basic resources essential to the rapid development and successful execution of industrial projects. From the earliest times down to the present, the ascent of man, his growing culture and civilization, his advancement, the story of man's progress have been closely linked with minerals and mineral substances. Man has to look to minerals for his festivities, even for his funeral rites.

In the branch of Mineralogy, the chemical properties, crystalline structure, physical properties and optical properties of minerals are studied. The study of minerals includes the individual minerals and their distinguishing properties, their mode of occurrence and their association.

The classification of economic minerals and rocks followed by Brown and Dey and adopted by Mining Journal of London on the basis of industrial utilization are as follows:

1. The fuels like coal, lignite, petroleum and natural gas.
2. The metals and their ores including
   (a) Precious metals like gold, silver and platinum.
   (b) Important non-ferrous metals like Copper, Lead, Zinc and Tin.
   (c) Ferrous and related metals Iron, Manganese, Nickel.
   (d) Steel industry minerals: Iron Ore, Nickel, Chromium, Cobalt, Tungsten, Molybdenum, Titanium, Columbium, Niobium, Tantalum, Vanadium.
   (e) Light metals like Aluminium, Magnesium and Lithium.
   (f) Radio active minerals like Uranium, Thorium, Caesium, Rubidium, Beryllium, Zirconium, Hafnium and rare earths.

3. Building and road making like building stones, brick and tile clays, limestone, gypsum, marble, granites, sandstones and other ornamental stones.

4. Ceramic and refractory raw materials and glass-making materials e.g. clays, china clays, dolomite, chromite, corundum, bauxite, sillimanite, kyanite and andalusite, graphite, zircon, talc, glass sands and moulding sands.

5. Minerals used in agriculture, such as saltpetre, potassium salts, phosphates, ammonium sulphate.

6. Minerals used in the paint and varnish industries such as red and yellow ochres, barytes.

7. Mineral used for insulation, such as asbestos, mica and vermiculite.

8. Industrial salts like sulphates of iron and copper, alum and related compounds, salt, sodium compounds and borax.

9. Other industrial minerals like sulphur, steatite and pyrophyllite, Fuller's salt, bentonite, fluorspar, strontium minerals, mineral waters and zeolites.

10. Precious stones like diamonds, rubies, sapphire and emeralds, semi-precious stones like agate, amethyst, onyx, carnelian, blood-stone, opal, moonstone, spinel, topaz, garnet, zircon, chrysoberyl, perodol, lapis lazuli and turquirse.

Some useful definitions

A mineral which may be utilised in extracting one or more metals or metallic compounds at a profit, is known as an *Ore-mineral.* Thus Galena is an Ore-mineral for lead. In nature, ore minerals are usually associated with some non-metallic minerals. These are known as *Gangue minerals.*

Thus, quartz remains as a gangue mineral in many ore-minerals including galena. The term *Gangue* is however sometimes applied to any useless material associated with ore-minerals. But a worthless gangue of today may turn into a valuable substance in course of time An *ore* is an aggregation of ore mineral and gangue from which metal or metallic compounds may be extracted profitably. The minimum metal content of an ore which would ensure its profitable extraction is known as its Tenor.

The *Mineral deposits* includes both metalliferous and non-metalliferous deposits. Metalliferous deposits are sought for the metals they contain, which are extracted generally in the metallic state Thus, Singhbhum deposits of copper, lead-zinc deposits of Zawar in Rajasthan etc. are examples of Metalliferous deposits. The *Non-metallic mineral* deposits include useful materials like coal, petroleum, mica, gypsum, gemstones, etc. The geological formations

during which the metallic and non-metallic mineral deposits were formed in certain parts of the earth are known as *Metallogenetic periods.* The Pre-cambrian age is one of the important metallogenetic periods when many large deposits of iron, manganese, copper, lead, gold, zinc, silver, nickel, tungsten were formed in this period. certain regions of the globe in which a particular type of mineral deposit has been produced as a result of abundant mineralization during the metallogenetic periods are called *metallogenetic province.* Thus, the iron ore deposits of Singbhum, Bihar, Gonditic manganese deposits of Madhya Pradesh are examples of metallogenetic province.

The *hypogene or primary minerals* are those which were deposited during the original period or periods of mineralisation. The word hypogene indicates formation by ascending solutions, e.g., Sedimentary hematite. *Supergene or Secondary minerals* are alteration products of the primary are minerals as a result of weathering and erosion resulting from descending surface waters. For example, feldspathic rocks are converted into kaolin masses by weathering. *Syngentic mineral* deposits are formed along with the enclosing country rocks, e.g. sedimentary iron deposits. *Epigenetic mineral* deposits are formed later than the rocks enclose them, e.g., magnetite deposits of Kiruna, Sweden. The *base metals* are so called because they are 'base' or 'mean' compared to gold and silver which are called 'noble' metals. *Beneficiation* is a process by which ore minerals may be upgraded. Beneficiation can be done in any one of the following : (i) By hand sorting, (ii) By simple washing and size grading, (iii) Heavy medium separation, (iv) By Electro-magnetic separation.

Mineral, occurs naturally in the earth's crust which consist chiefly or organic hydrocarbons, which is used for producing heat energy, either by means of the release of its chemical energy by combustion or its nuclear energy by nuclear fission, which are called *Mineral fuel*, such as coal, petroleum, atomic or radio active minerals. The remains of organisms embeded in the surface of the earth, with high carbon and hydrogen contents which are used as fuels, which are called *Fossil fuels*, such as Petroleum, coal, etc. *Water* is a mineral and is a compound of Hydrogen and Oxygen. *Natural water* (water of river, spring, rain, lake, etc.) is never quite pure contains dissolved substances. The water that is obtained from the great depths of the earth's crust is known as *magnatic water*. The water that is entrapped in sedimentary rocks during their formation is called *connate water*.

Rocks are aggregates of minerals and which forms the part of the earth's crust. Rocks can be broadly divided into three main classes (i) Igneous, (ii) Sedimentary, (iii) Metamorphic. Igneous or primary rocks are formed by the consolidation of magma, e.g., granite, syenite,

Other minerals for example, the three minerals, rutile, anatase and brookite, all forms of titanium oxide (TiO_2) exhibit trimorphism. Mineral, such as sulphur with more than three different crystalline modifications are said to be *trimorphous*.

CHEMISTRY OF MINERALS

Matter : The materials which has weight occupies space and can b. moved by a force is called *matter*. A particular type of matter is called substance. Matter may exist in three states, namely the solid, the liquid and the gaseous. A solid has a fixed volume and shape. Most of the minerals are solid, as for example calcite, siderite, etc. Liquids and gases are called fluids, a liquid has a fixed volume, but no fixed shape, petroleum, water etc., are example of mineral in liquid state. Gas has no fixed shape or volume and Natural gas is one of its example.

Element, Compound and Mixture : Matter can be divided into mixture and pure substances. Pure substances may be divided into two classes, viz., elements and compounds. *Elements* are substances which has not been split up by any chemical analysis into simpler substances. Examples of elements are iron, copper, manganese, etc. *Compounds* are substances made up of two or more essentially dissimilar substances and are formed by the union of two or more elements as a result of chemical change. Quartz, water are examples of compounds. *Mixture* differ from chemical compounds. A compound cannot easily be separated, whereas the components of a mixture can usually be separated by mechanical means. The rock granite is a mixture of several minerals.

Atoms and Molecules : An *atom* is an indivisible unit of an element which can play a part in chemical reactions. The *atomic weight* of an element is the weight of an atom compared with that of an atom of oxygen, taking oxygen to be 16.

The atoms built up of still smaller units called *electron* which carries a unit *negative* charge and *proton* which carries a unit *positive* charge. A electrically charged atom or group of atoms are called *ions*. Positively charged are called *cation* and negative charged ions are called *anion*.

The *molecule* may be defined as the smallest portion of substance capable of existing independently and retaining properties of the original substance. Molecules may consist of one atom as in the helium gas or two atoms of the hydrogen unite to form a molecule of hydrogen gas.

The *molecular weight* of a substance is a number which is the sum of the atomic weights of the atoms composing a molecule of the substance.

Symbols and Formulae: A *symbol* is an abbreviation of the English or Latin name of the element, which is usually first letter or first and second letter of the full name of the element. O is the symbol of an atom of oxygen and Ca is the symbol of an atom of Calcium. *Molecule* is the symbolic representation of the molecule of of a substance.

Valency: The *valency* of an element is given by a number of its atoms which will combine with or replace one atom of hydrogen or chlorine, e.g. the valency of oxygen in water H_2O is 2. Some of the elements have different valencies is different compounds:

$Na - Cl \quad Ba = Cl_2 \quad Au \equiv Cl_3 \quad Sn \equiv C$ etc.

Metals and Non-Metals: The elements may be divided into two distinct classes, the metals and the non-metals. A *metal* is a substance having a metallic lustre, malleability, ductity, high specific gravity, and a conductor or heat and electricity. *Non-metals* are, if solid brittle, often transparent to light radiation, are poor conductors for heat and electricity. They usually play the acid part in a chemical compound.

Metals: Fe, Cu, Pb, Zn, Au, Mn, As, Sn etc.

Non-mentals: O, N, S, Si, Cl, H etc.

Periodic Law: The properties of the elements are in periodic dependance upon their *atomic weights*. The elements may be divided into groups so the elements of similar properties are brought together. An arrangement of elements having similar properties occur at regular intervals and fall into groups of related elements and was first shown by Mendeleef in the *Periodic Table*.

Radicals, Oxides. Acids, Bases, Salts: A compound of two or more elements according to their valency which one or more bonds, is usually incapable of independent existence, is called *radical*. An oxide is a binary compound of Oxygen with another element, e.g. corundum (Al_2O_3) and quartz (SiO_2). The oxides of non-metals are acidic and most of them are soluble in water to form acids. All acids are compound containing hydrogen, a part or whole of which may be replaced by a metal or a group of elements acting like a metal to produce salt. A group of atoms combined with the hydrogen is called *acid radical* e.g. Sulphur, Carbon, Nitrogen, etc. The oxides of metals are called *basic redicals*. Some oxides of metals combine with water to form bases. Examples are: Brucite, $Al_2(OH)_6$. A

base is a substance usually oxide of a metal which can neutralise an acid to produce a salt and water only. *Salts* are formed by the combination of an acid and base, the hydrogen of the acid is replaced by the metal of the base and to produce a salt. Salts are usually named after the names of acids from which they are formed. Examples are : Flourspar (CaF_2), Galena (PbS)

Water of Crystallisation, Oxidation, Reduction.

Synthesis and Analysis

Water of Crystallisation : A definite molecular proportion of water chemically combined with certain minerals in the crystalline state. Examples are : Borax has ten molecules of water of crystallisation as ($Na_2B_4O_7$, $10H_2O$) and gypsum has two as (Ca_2SO_4, $2H_2O$) Gypsum and Borax are called hydrated oxide.

Oxidation : A combination of oxygen with a element or compound is called oxidation. A metallic copper is heated in air and the oxidation of copper takes place to form a black oxide of copper. Reduction means ordinarily removal of oxygen. When copper oxide is heated in a current of Hydrogen, it is reduced into metallic copper, i.e. Oxygen is removed from CuO. The formation of a compound by the union of one element with other elements are called *synthesis.*

The decomposition of a compound into their constituent parts or elements is called *analysis.* The determination of the nature of elementary substances contained in a compound is called *qualitative analysis.*

The determining the proportions of the constituent parts of a compound is called *quantitative analysis.*

Reagents, Solubility, Fusibilty

Reagents : The most commonly used chemical reagents are Hydrochloric acid, Nitric acid and Sulphuric acid. Ammonium hydroxide, Barium chloride, Silver nitrate, Ammonium molybdate, Ammonium oxalate and Distilled water are also used as chemical reagents. *Solubility :* In most cases hydrochloric acid is used to make the solutions of the minerals. In case of metallic minerals, such as sulphides and compounds of lead and silver, nitric acid is used. In some cases sulphuric acid and aqua regia (nitro—hydrochloric acid) are also required. Limonite, Hematite, Goethite etc. are completely soluble without effervesence. Platinum and gold are soluble in aqua regia. Calcite, Siderite, Sphalerite, Stibnite psilomelane, cuprite etc., the soluble with effervecence. Quartz, chromite, rutile, corundum spinel, etc. are insoluble minerals.

Fusibility: The fusibility of certain minerals is a useful character of their identification by the blow pipe.

The chemical analysis or tests alone are not conclusive in the identification of a mineral and must be used together with a study of its physical properties for the said purposes. Anyway, chemical tests are most helpful in differentiating between two minerals of similar physical nature and differing in their chemistry e.g. barite ($BaSO_4$) and celestite ($SrSO_4$) or determining certain e.g. stibnite, molybdenite etc. However, as said earlier conclusive identification should not be made without studying the physical properties of a mineral.

Most of the tests performed are dry tests only a few wet tests being used for confirmation of basic or identification of acid radicals. The tests are performed in the following order:

1. Closed tub test. 2. Open tube test. 3. Charcoal test in oxidising flame. 4. Charcoal test in reducing flame with sodium carbonate. 5. Cobalt nitrate test. 6. Flame test. 7. Borax bead test. 8. Microcosmic salt bead test. 9. Special test. 10. Test for acid radicals.

All tests should be performed, even if reactions are negative, because it is necessary to prove absence of elements other than those which have been detected. The mineral whose chemical test is to be performed, is ground and finally powdered in a porcelain mortar pestle. In case of harder minerals this done in an agate mortar pestle.

GLASS TUBE TEST

The glass tube tests are of two types: Closed tube tests and Open tube tests. The reactions used in closed tubes and open tubes are of great importance in chemical analysis of minerals. The closed tube consists of a harder glass tubing with about 5mm interior diameter cut into 3 inches in length, sealed off at one end. The open tube consists of soft tube of 3 mm in length open at both ends. A small quantity of powdered mineral is taken near the closed end of a closed tube and heated strongly. The sublimate is formed in cooler parts of the tube and the colour and nature of the sublimate may indicate one or more elements present in the mineral. The mineral powdered is placed at the bend portion of the open tube and heated in air and is oxidised. The characteristic sublimates or smells are formed.

CLOSED TUBE TEST

The powdered minerals heated in closed tube either alone/or with sodium carbonate and charcoal powder or with magnesium and water.

MINERAL	OBSERVATION
Sulphur ..	.. Yellow sublimate
Arsenic sulphide ..	.. Black sublimate with garlic odour.
Sulphide of Iron, Copper, Zinc, etc. ..	.. Red to dark yellow liquid, volatile when hot and yellow crystalline sublimate when cold and gives off pungent smell of SO_2.
Sulphide of Antimony ..	.. Brownish-red sublimate when cold and black sublimate when hot.
Sulphide of Mercury ..	.. Black sublimate.
Mercury ..	.. Heat with sodium carbonate and charcoal powder; globules of mercury as sublimate.
Arsenic ..	.. Heat with sodium carbonate and charcoal powder, black mirror of arsenic, strong garlic odour.
Phosphate ..	.. Heat with magnesium and water; gives off smell of H_2S.

OPEN TUBE TEST

MINERAL	OBSERVATION
Arsenic	White crystalline sublimate, volatite, away from the assay, strong garlic odour when slowly heated.
Aluminium	Straw yellow sublimate when hot and white sublimate when cold, near assay.
Sulphur	Sulphurous fumes of sulphur dioxide.
Mercury	When heated with potassium iodide and sulphur powder, greenish-yellow reside and fumes obtained.

COBALT NITRATE TEST

Powdered minerals are made a paste with a drop of cobalt nitrate solution and heated on a charcoal block in the oxidising flame.

MINERAL	OBSERVATION
Zinc	Grass-green assay when cold.
Tin	Bluish-green coloured assay formed.
Aluminium	Blue coloured assay formed.
Magnesium	Pink coloured residue.
Fusible Silicates, phosphates and borates	Glass-looking fused blue residue.

HEATING ON CHARCOAL IN THE REDUCING FLAME

Powdered minerals mixed with powdered charcoal and sodium carbonate and heated in the reducing flame.

MINERAL	OBSERVATION
Iron ..	.. Strongly magnetic residue.
Nickel and Cobalt ..	.. Feebly magnetic residue.
Copper ..	.. Red metallic scales.
Mercury ..	.. Grey mirror forming into globules.
Molybdenum ..	.. Pale yellow when hot ; turns white when cold ; sulphurous fumes.

HEATING ON CHARCOAL IN OXIDISING FLAME

Powdered minerals heated alone in oxidising flame in the groove of the charcoal block.

MINERAL	OBSERVATION
Arsenic ..	.. White volatile sublimate away from assay, yellow near assay, garlic odour.
Antimony ..	.. Dense white sublimate near assay, bluish away from assay.
Zinc ..	.. Mass incandescent and yellow when hot, white when cold.
Iron ..	.. Black magnetic residue.
Lead ..	.. Dark yellow sublimate when hot, yellow when cold, bluish white away from assay.

Sulphur	Smell of sulphur dioxide.
Tin	Faint yellow to white sublimate when hot, white when cold.
Bismuth	Orange when hot, paler orange when cold, when heated with potassium iodide and sulphur powder.
Silver	White metallic residue, no sublimate.
Lead	Soft malleable metallic lead easily fused, marks paper.
Gold	Yellow lead, soft and malleable.

FLAME TEST

A clean platinum wire moistened with conc. HCl, a little amount of the powdered minerals, taken at the clean platinum wire, is heated in the oxidising flame (silicates and phosphates do not respond).

MINERAL	OBSERVATION
Zinc ..	.. Green flame
Strontium ..	.. Crimson red flame
Arsenic ..	.. Blue flame
Calcium ..	.. Persistent brick-red flame
Copper ..	.. Emerald greenish flame
Barium ..	.. Yellowish green flame
Lead ..	.. Pale blue flame
Sodium ..	.. Yellowish flame
Potassium ..	.. Violet flame

BORAX BEAD TEST

A bead of borax on the loop of a platinum wire is made, the colourless bead is placed on the powdered mineral and is heated in the bunsen flame.

MINERAL		OBSERVATION		
		In Oxidising Flame		In Reducing Flame
Chromium	..	Yellowish green	..	Green
Iron	..	Yellowish	..	Bottle green
Copper	..	Greenish blue	..	Opaque red
Manganese	..	Violet	..	Colourless
Cobalt	..	Deep blue	..	Deep blue
Nickel	..	Reddish brown	..	Opaque grey

MICROCOSMIC BEAD TEST

Procedure is the same as for borax bead test except that Microcosmic salt Na (NH_4) HPO_4 is taken instead of Borax.

MINERAL		OBSERVATION		
		In Oxidising Flame		In Reducing Flame
Copper	..	Blue coloured bead	..	Opaque red coloured
Chromium	..	Red when hot, green when cold	..	Green
Manganese	..	Violet	..	Colourless
Iron	..	Colourless to brownish red	..	Reddish
Molybdenum	..	Green	..	Green
Titanium	..	Colourless	..	Yellow when hot, Violet when cold
Tungsten	..	Colourless bead	..	Bluish green
Cobalt	..	Blue	..	Blue
Nickel	..	Yellow	..	Reddish yellow
Silica	..	Insoluble residue		

SPECIAL TEST

MINERAL	OBSERVATION
Iron ..	.. Powdered mineral when heated with dil. HCl, brown red solution, turn blue on addition of K-ferrocyanide.
Copper ..	.. When heated with dil HCl, green solution turning intense blue on addition of NH_4 (OH).
Lead ..	.. Dissolved in Conc. HNO_3 and added KI solution, shinning golden yellow precipitated is deposited.
Titanium and Tungsten	.. Powdered mineral with charcoal powdered and sodium carbonate, the residue with dil. HCl and grains of granulated tin. Violet solution in case of titanium and blue solution in case of Tungsten.

TESTS FOR ACID RADICALS

MINERAL	OBSERVATION
Carbonate ..	.. Powdered mineral heated with dil. HCl, Carbon dioxide evolved, turns lime water milky.
Sulphide ..	.. Heated with dil. HCl. sulphurated hydrogen evolved, which turns lead acetate paper grey.
Chloride ..	.. Heated with H_2SO_4 and manganese dioxide, greenish chlorine evolved.

Fluoride	.. ..	Heated with powder and $KHSO_4$, a ring of white sublimate forms.
Phosphate	.. ..	Heated with HNO_3 and ammonium molybdate, yellow precipitate is deposited.
Sulphate	.. ..	Heated on charcoal block with Na_2CO_3 and charcoal dust, dil. HCL is added to the residue H_2S gas evolves which turns lead acetate paper black.
Nitrate	.. ..	Heated with H_2SO_4, brown nitrous fumes evolved.
Higher Oxide	.. ..	Heated with conc. HCl, gas of disagreeable odour, bleaches litmus paper.

PHYSICAL MINERALOGY

The physical mineralogy is a part of mineralogy which includes the study of physical properties of minerals which are very useful criteria in the identification of minerals.

The major part of all mineralogical identifications are in fact based only on physical properties and any student of mineralogy must be thus fully conversant with these methods. Each mineral has its own set of more or less distinctive physical properties so that even in the absence of chemical analysis, remarkably satisfactory indentifications may be made by means of simple physical tests. The physical properties include (1) Colour, (2) Streak, (3) Lustre, (4) Structure and form, (5) Cleavage, (6) Fracture, (7) Hardness, (8) Specific gravity, (9) Reaction with hydrochloric acid, (10) Magnetism and (11) Special properties.

Colour : The colour of a mineral is one of the most striking physical properties. Many minerals are identified readily by their constant and definite colour. Examples are : Kaolinite (chalk white); Dolomite (marble white); Psilomelane (black); Tourmaline (pitch black); Sulphur (yellow); Cinnabar (red); Galena (lead grey); Chalcopyrite (golden yellow), etc.

Streak : The streak of a mineral is the colour of its powder and may be quite different from that of the mineral in lump. It is a very important factor in mineral identification, and is obtained by rubbing the mineral concerned on an unglazed and rough porcelain plate known as the streak plate. Examples are : Hematite (cherry red); Sulphur (yellow); Graphite (lead grey); Magnetite (black); Psilomelane (brownish black), etc.

Lustre : The lustre of a mineral is the manner in which light is reflected from its surface. A most important distinction must be made between those minerals which have a metallic lustre and those which have not the former being always opaque. Lustre is described by the following terms.

A. *Metallic* lustre : the lustre of metals; e.g. galena, pyrite, etc.

B. *Sub–metallic* lustre :

(i) *Adamantine :* the most brilliant lustre; e.g. diamond.
(ii) *Vitreous* or Glassy : the lustre of glass, e.g. quartz.
(iii) *Sub-vitreous :* the imperfect glassy-lustre; e.g. Calcite.

(iv) *Pearly :* the lustre of pearly e.g. talc, stilbite, feldspar, mica.
(v) *Resinous :* the lustre of resin ; e.g. sphalerite, Sulphur.
(vi) *Greasy :* the lustre of oily glass ; e.g. Opal.
(vii) *Silky :* the lustre of silk ; e.g. gypsum, asbestos.
(viii) *Earthy :* the lustre of clay, e.g. Kaolinite.

Further lustre is described to its degree as :

(i) *Splendent* (gives well defined images) as in galena.
(ii) *Shining* (gives ill defined images) as in Hematite, Pyrite, etc.
(iii) Dull (no images are found) as in Kaolin, Pyrolusite etc.

Structure and Form : Some minerals generally occur in definite geometric arrangements, that is they are bounded by definite plane surfaces (faces) which developed when the minerals were formed. Such minerals are said to be *crystalline.* Other minerals are *amorphous* (non-crystalline) and have a definite shape. The term 'massive' may be used to convey lack of outer geometric form in a specimen which may yet be crystalline in structure.

Minerals very often possess a definite pattern in their internal atomic structure when they are said to be *crystalline.* If however, any such regularity is singularly absent then the mineral concerned is called *amorphous.* An intermediate group may be called *cryptocrystalline* when the said regularity is apparent only under high power microscope.

It is to be clearly understood that not all crystalline minerals show crystal faces, or so called *crystals.* Even a massive mineral may be perfectly crystalline minerals may be described as :

Columnar : showing a form resembling slender columns, e.g. beryl, hornblende, Extreme varieties are sometimes further described as *acicular* (needle shaped crystals) or *fibrous* (fibrous aggregates as in asbestos).

Lamellar : producing thin laminae, e.g. galena. Besides, other peculiar forms are :

Botryoidal : small spherical or rounded protruberances, e.g. smithsonite, limonite, psilomelane, etc.

Dendritic : like branching tree, e.g. Wad (manganese).

Nodular : irregular tuberose forms over the surface, e.g. chalk, azurite, etc.

Drusty : covered with minute implanted crystals e.g. quartz.

Pisolitic : an aggregate of small rounded masses, e.g, bauxite,

Oolitic : an aggregate of small spheres, e.g. hematite, soliceous, oolite, etc.

Fibrous : Consisting of fine thread-like strands, e.g. Fibrous gypsum.

Earthy : an uniform aggregation of exceedingly minute particles which produce a more or less firm consistency, e.g. Kaolin.

Micaceous : an aggregate of mineral which can be split easily into thin sheets, e.g. hematite.

Granular : an aggregate of crystalline particles of same size, e.g. dolomite.

Mammillary : an aggregate of bigger rounded masses e.g. chalcedony.

Stalactitic : A cylindrical or conical form, e.g. calcite.

Pseudomorph : False form, e.g. Limonite.

Stellated : Star like.

Tubcrose : Like the roots of tree.

Foliated or Foliaceous : Consisting of thin and separable lamellae or leaves, e.g. mica.

Bladed : knife blade shaped crystals e.g. kyanite.

Radiating or divergent : showing crystals a fibres arranged round a central point, e.g. stibnite.

Reniform : kidney shaped, e.g. goethite.

Cleavage : The crystallised minerals have a tendency to split along certain definite planes. These planes are so called the cleavage planes and the property is known as *cleavage.* Cleavage is described according to its perfection as (a) perfect, imperfect, etc. and (b) number of sets as (i) one set, e.g. graphite, stibnite., etc., (ii) two sets, e.g. kyanite. (iii) three sets, galena, calcite, etc. (iv) four sets, e.g. fluorite, (v) six sets, e.g. sphalerite.

Fracture : Fracture is the nature of broken surfaces of minerals. Fracture is thus described as :

(i) *Conchoidal :* the mineral breaks with a curved concave or convex fracture, e.g. quartz, opal, psilomelane.

(ii) *Even :* the fracture surface is flat, e.g. chert.

(iii) *Uneven :* the fracture surface is rough by reasons of minute elevations and depressions, e.g. feldspar, pyrolusite, etc.

(iv) *Hackly :* the surface is studded with sharp and jagged elevations, e.g. fibrous sillimanite.

Hardness : The hardness of a mineral is an important property for identification of a mineral in hand specimen and is defined as its resistance to abrasion by, or its ability to abrade, other substances.

In practice this is measured by scratching plates of known hardness with an unknown mineral. An arbitrary scale of hardness known as Moh's scale of Hardness (given below) is long in use as a standard where ten minerals are arranged in order of increasing hardness, from talc (1) to diamond (10). Other minerals are referred to this scale; for instance, mineral harder than Orthoclase (6) but softer than quartz (7) is said to have a hardness of 6·5 and so on.

Moh's Scale of Hardness

Hardness	*Standard Minerals*
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase
7	Quartz
8	Topaz
9	Corundum
10	Diamond

In practice, however, the following scale is found to be very useful:

Finger nail	Hardness about 1 — 2·5
Brass plate	Hardness about 2·5 — 3·5
Iron plate	Hardess about 3·5 — 5
Glass plate	Hardness about 5 — 6

Specific Gravity [Heaviness]: The specific gravity of a mineral is the ratio of its weight to that of an equal volume of water. Accurate determination of this property can be made by (i) Jolly's Spring Balance, for very small specimens; or by (ii) La Touche's Steel yard, for large specimens, or even by other such mechanical means. For ordinary purpose, however, a rough approximation can be made by holding the mineral in the palm of one hand and comparing its weight with its volume. A little experience will soon be enable one in describing specific gravity as;

(i) Low (2·5): e.g. Graphite, Sulphur, Halite, Opal.
(ii) Moderately low: (2·5—3·5) e.g. Fluorite, Quartz, Talc Muscovite, etc.

(iii) High (3·5—7): e.g. Sphalerite, Chalcopyrite, Pyrite, etc.

(iv) Very high (7·0 and above) e.g. Galena, Cinnabar, etc.

Jolly's Spring Balance: This balance consists of a spring (a) suspended vertically against mirror scale (b) which is graduated and fixed in a wooden frame (Fig. 1). Two scale — pans, one below the other, are attached to the lower end of the spring, the lower scale pan being immersed in water. The reading (A) of the bottom of the spring, on the scale is obtained. The mineral whose specific gravity is to be determined is then placed on the upper pan and a second reading (B) is taken. The mineral is then transferred to the lower pan and a third reading (C) is taken. Throughout the experiment, the lower scale pan is always to be kept immersed upto a constant height under water contained in a breaker resting on a movable wooden platform.

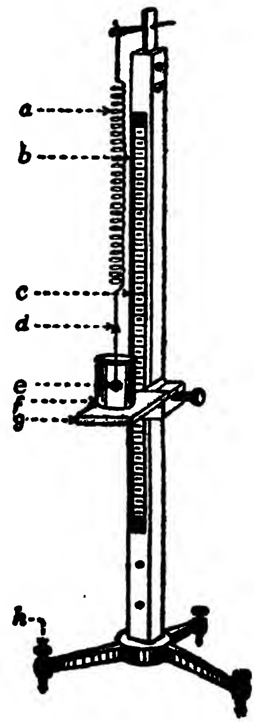


Fig. 1. Jolly's Spring Balance a. Spring ; b. Graduated Mirror ; c. Wooden Frame ; d. Upper Pan ; e. Lower Pan ; f. Beaker ; g. Wooden Platform ; h. Levelling Screw.

The difference between the reading B—A in thus proportional to the weight of the mineral in air, and B—C to the loss of weight in water, sothat:

$$\text{Specific gravity} = \frac{\text{Wt. of mineral in air}}{\text{Loss of weight in water.}} = \frac{B-A}{B-C}$$

La touche's Steelyard Balance: The apparatus consists of a graduated beam which is pointed near one of its end and has an adjustable nut on the other end, and rests on a fulcrum.

The specimen is suspended at the end of the short arm and a fixed weight is moved along the beam until it counter-balances the constant weight. The horizontal position of the beam, when obtained, will be shown by the pointer of the steelyard moving on a vertical scale in a rectangular frame. The first reading (X) is taken. The

specimen is then immersed in water and the pan with constant weight is again slided till horizontally is achieved and a second read-

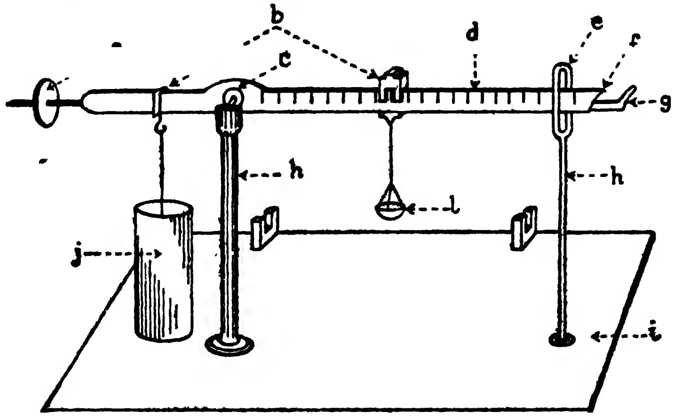


Fig. 2. La Touche's Steelyard Balance
a. Weight, b. Hook c. Fulcram, d. Graduated beam, e. Ring, f, Pointer, g. Vertical Scale, h. Pillar, i. Wooden platform. j. Water container, k. Pan.

ing (Y) is taken. Then, weight of the mineral in air is X and the loss of weight in water is X–Y

$$\text{Hence, Specific Gravity} = \frac{\text{Wt. in air.}}{\text{Loss of wt. in water}}$$

$$= \frac{X}{X-Y}$$

Reaction with hydrochloric acid: Effervesence with the evolution of Carbon dioxide in dilute Hydrochloric acid; e.g. Carbonate minerals; (calcite, dolomite, etc.).

Liberation of Sulphuretted Hydrogen when applied to some sulphides, e.g. galena, Sphalerite, etc.

Magnetism: Certain minerals are attracted by a magnet in powder form, e.g. Ilmenite (weakly magnetite, strongly magnetic).

Special properties: Other special properties are:

(i) *Odour:* earthy smell; e.g. Kaolin, Bauxite, sulphur smell, e.g. Sulphur.

(ii) *Feel:* greasy feel, e.g. Talc.

Solubility in water: e.g. Halite.

Invisibility in water: e.g. Cryolite.

Taste: as saline, e.g. Halite.

Marking paper and soiling hand: graphite, pyrolusite, galena.

CRYSTALLOGRAPHY

Crystallography is a part of mineralogy dealing with the science of crystals in their development and growth, their crystalline form and internal structure. *Crystals* are solids bounded by flat surfaces, arranged on a definite pattern which is an expression of internal atomic structure. The process, by which a crystal is formed by the solidification of minerals from the states of liquid or gas, is called *Crystallisation.* If a crystal is formed with flat surfaces or crystal faces, it is said to be *euhedral.* When a mineral is formed with partially developed plane surface or crystal face, is said to be *sub-hedral* and when a mineral is formed with no plane surface, is said to be *anhedral.*

When a mineral shows the external form and atomic structure, it is said to be *crystal.* A mineral, which possesses only the internal atomic structure without showing the corresponding external structure, is termed a *crystalline.*

When a mineral is incapable of developing of both external form and internal atomic structure is said to be *amorphous.* A mineral is said to be *massive,* when it shows no external structure. A very finely crystalline aggregate in which the crystals are so small as to be indistinguishable, except under microscope, is called *cryptocrystalline.* Mineral quartz occurs as crystal or in crystalline state or in crystalline aggregate. Agate, chalcedony, chert, jasper, etc. are examples of cryptocrystalline and opal is an example of amorphous state.

Crystal aggregates are made up of two or more crystals. If the crystalline structure of the minerals varies from fibre to fibre and grain to grain, it is said to be *crystalline aggregate.* In crystalline aggregate, the crystals are so small as to be indistinguishable except under microscope. Crystal aggregate consisting of one mineral only, is said to be *homogenous aggregate.* If two or more minerals occur in the aggregate, it is called *heterogenous aggregate.* In a crystal aggregate if all the crystal occur in parallel position, in which the individuals have the same orientations, like edges and faces of the different crystals being parallels the arrangement is said to be *parallel growth.*

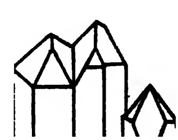


Fig. 3.
Crystal Aggregates group of quartz crystals shows parallel growth.

Twin Crystals are made up of two or more parts consisting of the same substance, which are joined together in such a way that some crystallographic direction is common to the parts of the twin. In homogenous crystal aggregates, some crystallographic direction is common to two or more individuals and they are called *twinned crystals*. A plane, which divides the twin crystal so that one half is a reflection of the other half is called *twin plane*. The axis about which rotation through an angle of 180° is necessary to restore the twin to its untwinned position is called the *twin axis*. The plane along which the two halves of a twin crystal are joined, is defined as the *Composition plane*. There are various types of twiness the following are the most important :

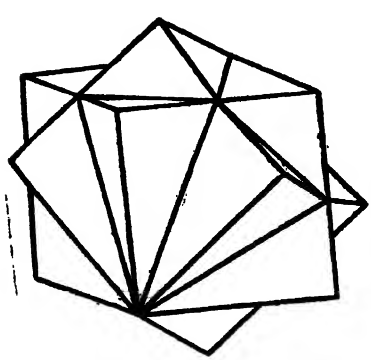
Simple twin or Contact twin: The two halves of the twin crystal is symmetric to the composition plane, one half will be mirror image of the other, this type of twining is called *Simple Twin,* e.g. the twin of Calcite.

Penetration twin : The two halves of the twin crystal have grown in such a way that the twin cannot be separated into two halves, e.g. the twin of flourite.

Repeated or polysynthetic twin : If the twin plane in all parts of the repeated twin are parallel, then it is called *polysynthetic twining*. Polysynthetic twinning is shown in plagioclase feldspar.

Compound or Complex twin : A twin in which twinning has taken place on different twinning processes.

Twisted Crystals : Some crystals split in the course of growth and the splitting is due to the presence of foreign materials in the melt, the temperature variations, the rapid growth of large size of the crystal and mechanical damage.



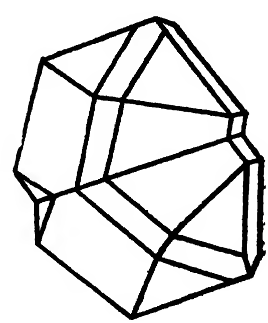
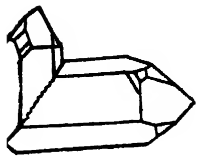
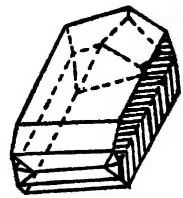


Fig. 4.

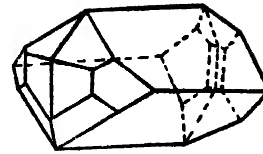
a. Spinel twin b. Rutile twin



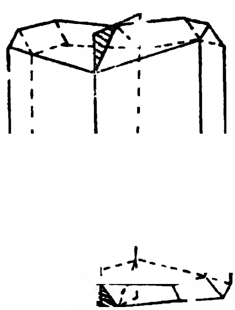
c. Japan twin



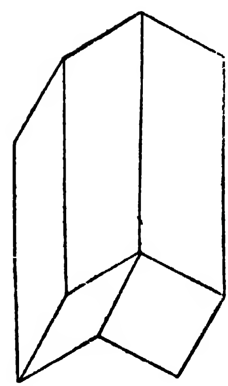
d. Manebach twin



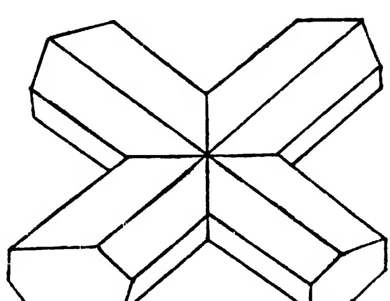
e. Baveno twin



f. Albite twin



Simple twin



h. Penetration twin

Twin Laws

Albite twin, in which the twin plane is (010), the brachypinacoid. Albite twining is usually repeated and polysynthetic and it is observed with Plagioclase feldspar. *Carlsbad twin*: In this the twin axis is the Vertical Crystallographic axis and the composition plane is the clinopinacoid. It is observed with orthoclase. In the *Manebach twin,* the twin plane and the composition plane are the basal piñacoid (001). It is observed with orthoclase feldspar. In the *Baveno twin, the plane* and composition-plane are the clinodome (021). It is also observed with monoclinic crystals (orthoclase). *Dauphine twin :* twin crystal with the same rotation are intergrown so that their three fold axes arc parallel but at the same time one crystall is turned 180° with respect to the other. In *Brazil twin* two crystals of different rotation are intergrown so that their three fold axes are parallel and the face is the twin plane. In *Japan twin,* two crystals are intergrown on the face, which is the twin plane and prodgeniculate forms; Dauphine, Brazil and Japan twin are three types of Quartz twin (Hexagonal System). *Spinel Law,* in which the twin plane is the octahedral face and the twin axis is at right angles to this. It is observed with galena (*Isometric System*). *Rutile Law,* in which the twin plane and composition plane are a face of the pyramid of the Second order. This is the commonest type of twinning in the Tetragonal System. Staurolite forms two types of twins, the brachydome is the twin plane and twinning on this Law gives a "*Maltese Cross*" twin, "Skew twin" has a pyramid as twin-plane. "*Swallow-tails*" twin in which the orthopinacoid (100) as the twin plane.

According to Prof. E. Flint, the crystal twins have a symmetry higher or lower than single crystals, which is otherwise known as pseudosymmetry. Some twinned crystals of the Isometric system may have a six fold symmetary axis which can never be present in single crystals of this system.

Five cases of twin formation are so far known :

1. Twin crystals formed by parallel superposition of molecules on a twin nucleus which has sprung up from two or more molecules ;
2. Twin crystals formed by transition of one crystallographic modification into another (polymorphous transformation, e.g. Quartz).
3. Twin crystals formed by intergrowth of small crystals after their accidental contact during growth in a position conducive to twinning.

4. Twin crystals formed under the influence of mechanical factor.
5. Twin crystals formed by superposition of molecules in a twinned position on a large crystal.

Combinations of Crystals : So far we have considered isolated crystals, however, often occur as combinations, either, or *Parallel Gowth* or *Irregular Aggregates* or as *Twinned crystals.* Twins consist of two or more crystals of some minerals having a different orientation, but symmetrically related to each other. The presence of re-entrent angles is very characteristic of twinned crystals, for simple crystals usually have only salient interfacial angles.

There are many different types of twinning simple twins may be either contact twin can often be explained by imagining that reflection has occurred across a *twin plane ;* for the two haves are mirror images of each other. The line about which rotation might have taken place is called the *twin axis* and is usually normal to an important crystal face.

CHARACTERISTICS OF CRYSTALS

Faces, Forms, Habit, Edge, Solid Angle

Crystals are bounded by smooth plane or curved surfaces called *faces.* Crystal faces are of two kinds, like faces and unlike faces. Faces which have the same properties are said to be *like faces* and faces that have different properties are called *unlike faces.*

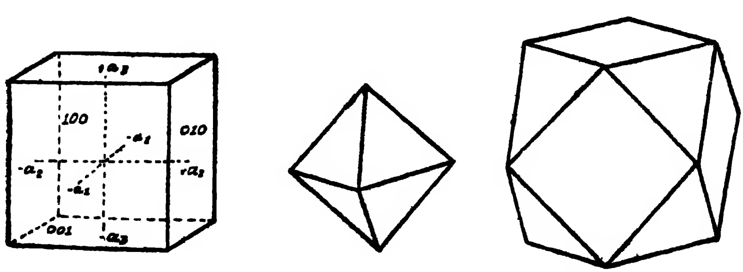


Fig. 5

a. Cube b. Octahedron c. Cube and Octohedron

In crystallography a form is said to constitute a group of faces generated from an initial face by the operation of the symmetry elements of a particular crystal class. A *form* includes all the faces which have a like position relative to the planes of symmetry or axes of symmetry. A crystal is bounded by all like faces are termed a *simple form.*

Examples are cube and octahedron when a crystal consists of two or more simple forms, is called a *combination form*. Galena crystal occurs in the combination form of cube and octahedron. A *open form* is an assemblage of faces which cannot enclose a volume in space and can only occur in combinations. Macro, Brachy and Basal Pinacoids are examples of open form. A *closed form* is an assemblage of faces which can enclose a volume in space. Pyramid is an example of closed form. Most crystals occur in *distorted forms*, having variation in the sizes of like faces and not in the same geometrically symmetrical position. Distorted octahedron is an example of these forms. Some common forms crystallising in the isometric system are cube, dodecahedron or rhombodo-decahedron, octahedron, etc. In other systems, the forms are Base, Prism, Pyramid, Pinacoid, Dome, ect. *Base* is that form which meets only the vertical axis and parallel to other axies. *Prisms* are forms whose faces are parallel to the vertical axis but meet both the horizontal axes. If the faces meet all the three crystallographic axes, the form is *Pyramid*. A face which cuts any one of the three crystallographic axes and parallel to the other two is called a *pinacoid*. If the faces are parallel to one horizontal axis only, the form is a *dome*. *Pedion* is a crystals form consisting of one face. Pinacoid or dome face occur in crystals belonging to the Orthorhombic, Monoclinic or Triclinic Systems. Pyramid and pedion face occur in crystals belonging to hexagonal system.

Habit of a crystal is referred to the relative development of individual faces and forms. Examples are Prismatic habit, Pyramidal habit, etc.

Edge : The adjacent faces always meet together along a straight line and the intersection of any two adjacent faces is called an *edge*. The class of crystal system in which the maximum symmetry (Normal Class) is displayed and the general form has the maximum number of faces is said to be *holohedral*. For an example, there are forty-eight faces in the isometric system. The class of a crystal system which has reduced symmetry, so that the general form has one *half* the number of faces of the corresponding form of the normal class (holohedral), is said to be *hemihedral*. For an example hemihedral form has twenty four faces, compared with forty eight in the holohedral class. *Hemimorphic* forms occur under the classes of lower symmetry than that of the normal class. These crystals lack both a centre of symmetry and a plane of symmetry perpendicular to the 'c' axis. A simple example under the hexagonal system is tourmaline. Crystal forms are said to be *enantiomorphous* which lack both a centre of symmetry and a plane of symmetry. An example under the hexagonal system is Quartz.

Solid Angle : The angle is formed by the intersection of three or more crystal faces, is called *solid angle*.

Zone : A *zone*, in a crystal, is formed by the faces so arranged that the edges formed by the intersections of adjacent faces, are parallel with one another. The line with which the parallel edges run is called the *zone-axis*. The crystal faces are arranged in zones. Simple numerical relation exists between all the faces of a crystal form in a zone, which is called *zonal equation*.

Interfacial Angles : The angle between any two crystal faces is called the *interfacial angle*. The interfacial angles of crystals are measured either by the contact goniometer or by the reflecting goniometer. The interfacial angle between the two faces of a crystals shown in fig. 6 is a

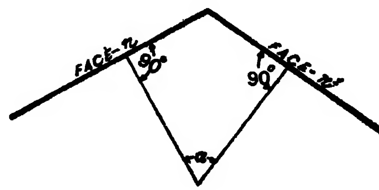


Fig. 6. The Interfacial Angle.

Contact goniometers are used for determination of interfacial angles between the faces of a crystal and in drawing its orthographic and

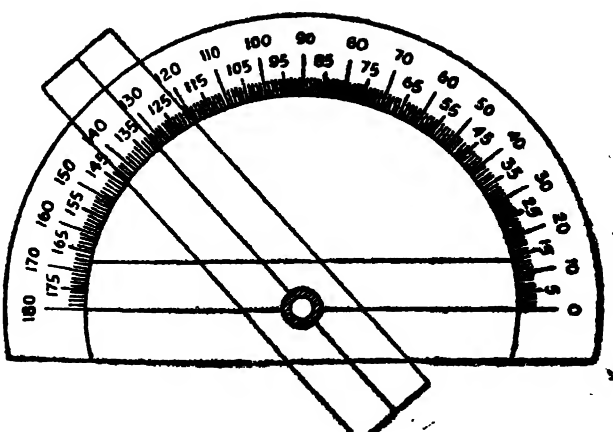


Fig. 7. Contact Goniometer

climographic projections. This instrument consists of a graduated (from 0° to 180°) semi-circular disc which is placed on the face while

the arm is brought in contact with the other faces. The reading at the other end of the arm gives the interfacial angle between the two faces of the crystal.

The *reflecting goniometer* consist of a graduated vertical circle, which can be rotated, a horizontal arm fixed at right angles to the plane of vertical circle and a mirror fixed on the arm. The reflecting goniometer is suitable for small crystals with brilliant reflecting faces. A crystal is mounted at the centre of the graduated vertical circle with one edge of the crystal parallel to the arm. The image of the source light, called signal is observed by reflection from the mirror, and also by reflection from the face of the crystal. The two images are made to lie in the same straight line, by rotating the vertical circle and the crystal. The graduated vertical circle is then rotated until the image is obtained by reflection from the adjacent face. The amount of rotation gives the angle of rotation which gives the interfacial angle, i.e. the angle between the normals to the two crystal faces.

The Law of Constancy of Interfacial Angles: Crystals of the same substance can have different habits depending on the number and size of faces, but the angles between the corresponding faces remain constant. The Law of Constancy of angle was first formulated by Nicholas Stensen in 1669. The constancy of interfacial angles was demonstrated by him for two substances: hematite (Fe_2O_3) and quartz (SiO_2).

Space Lattice: The space lattice constitutes the geometrical pattern or frame work of the internal structure of crystalline substances. The arrangement of atoms in the crystal is represented by points.

X-ray study of Crystals: Examination of crystals by X-ray has led to the determination of the relative positions of the different atoms in the crystal structure.

Symmetry: The most important attribute of a crystal is its symmetry. The symmetry of crystals is a symmetry of interfacial angles, which, in the rare cases of perfect and equally developed crystals, gives a symmetry of shapes, i.e. of distribution of faces of similar shape. The studies of crystal show that there is certain regularity of position of like crystal faces and edges, etc. The regularity of faces, edges, etc. are called. *Symmetry of Crystal.* The degree of symmetry varies in different minerals and the symmetry of a crystal may be studied and defined. The geometrical expression of a symmetry operation is called an element of symmetry. The elements

of symmetry are (a) Plane of symmetry (b) Axis of symmetry and (c) Centre of symmetry. A *plane of symmetry* divides a crystal into two similar or similarly placed halves so that one half is the mirror

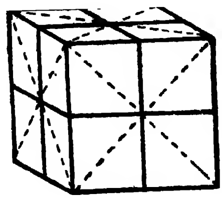


Fig. 8(a) Planes of Symmetry in the Cube.

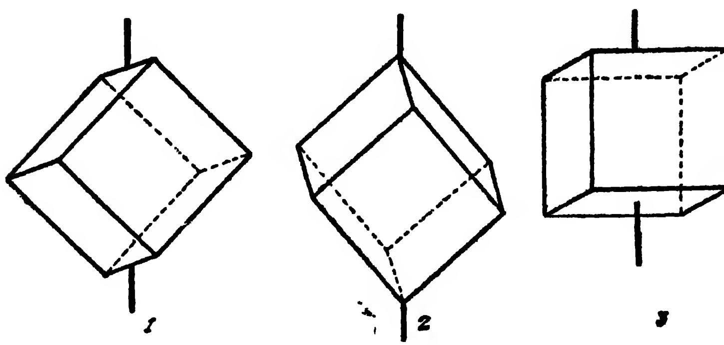


Fig. 8(b) Axes of Symmetry of the Cube

image of the other. A cube has nine planes each of which divides it into two halves so that one half is the reflection of the other. The *Axis of symmetry* is the axis which have the character of giving rise to the geometrically identical portions more than once in a complete rotation about it. Axis of symmetry are further designated as diad led to the determination of the relative position of the different (2 fold), triad (3 fold), tetrad (4 fold) and hexad (6 fold) according to the number of times the crystal presents identical aspect in one complete rotation. These are written as Ax_2, Ax_3, Ax_4 and Ax_6 respectively. A crystal is said to have a *centre of symmetry* if every face has an identical face as its antipodal (opposite sides of the central point) on the crystal.

Relation of Crystallographic and Geometrical symmentry : Crystallographic symmetry depends upon the internal atomic structure of the crystal than on the exact sizes of the faces developed. In determining the geometric symmetry of a crystal the stress is on the

accurate determination of the geometric form, size and shape of the crystal faces. The crystallographic symmetry should not be confused with geommetrical symmetry.

Crystallographic Axes, Parameters, Indices and Symbol: In describing a crystal specially in regard to the position of its face it is found convenient to assume certain lines passing to the centre of the crystal as a basis of reference. These lines are called the *crystallographic axes,* are determined by symmetry elements of the crystal.

The *parameters* of a face of a crystal are ratio of the distances from the origin at which the crystal face or any face parallel to it cut the crystallographic axes. The parameters of a plane consist of a series of members express ratios of the intercepts of that plane upon the crystallographic axes. The parameters of a plane consist of a series of numbers which express the relative intercepts of that plane on the corresponding crystallographic axes. They are expressed in terms of the established unit lengths of these axes.. In Fig. 9, mn, mo, mp, represent the crystallographic axes, and UTQ is a crystal face making intercepts of mu, mn, mT, mo and mQ on mp. The parameters of the face UTQ are given by the ratio of mu, mT, and mQ.

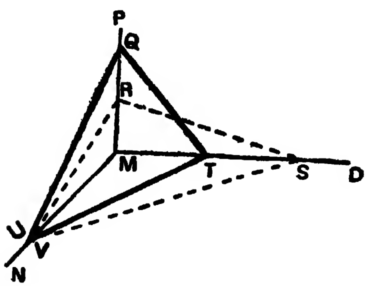


Fig. 9. Parameters

Indices: The reciprocals of the parameters are known as *indices* and are commonly used to give its relations to the crystallographic axes. It is also used for the purpose of crystallographic notation. The indices of its faces of the pyramid form of the Tetragonal System are above 111, 111, 111, 111; below 111, 112, 222, 222 (Fig. 10). (Here the negative indices are denoted as bars, e.g., 1 2 etc.).

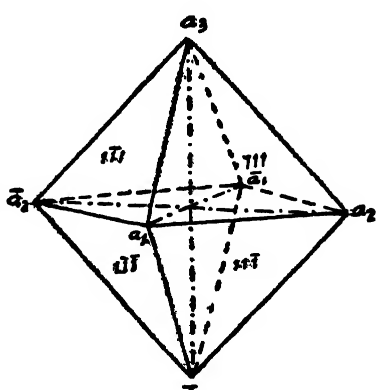


Fig. 10. Octahedron the form (111)

Symbol : The symbol is used to name the whole crystal form. The *symbol* of a crystal form is the indices of the face of that form which has the relations to the crystallographic axes. The symbol of

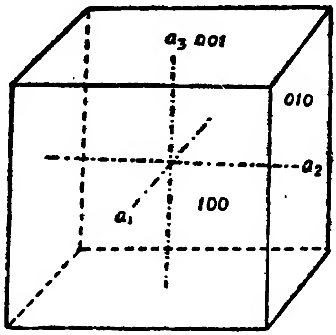


Fig. 11

the cube form of Isometric System is (100) and the form is made up of the faces 100 (front), $\bar{1}00$ (back), 010 (right), $0\bar{1}0$ (left), 001 (top) and $00\bar{1}$ (bottom). (fig. 11).

Axial Ratio, Axial Plane : In the crystal systems, except the Isometric system, the length of one of the horizontal axes is taken as the unit to which the lengths of other axes are referred ; hence the lengths of the axes express the *axial ratio.* The axial ratio of sulphur is

$$a : b : c = 0{\cdot}813 : 1 : 1{\cdot}903$$

The plane in which two of the axes lie, is called the *axial plane.*

Crystallographic Notation : Crystallographic notation is a brief method of using the relation of any crystal face to the crystallographic axes. Most of the systems of notation depend upon either indices or parameters. The index system of Millar and Parameter System of Weiss are used for the system of notation (See Fig. 10 & 11).

It is to be noted that for the indication of a crystal form, the symbols will be in a bracket thus (hkl) and the symbols of the crystal face will be without bracket thus hkl. The notation 100 indicates only one face of the crystal while the form (100) indicates all the faces. A crystal belonging to the isometric system, the form (111) includes all the eight faces 111, $1\bar{1}1$, $1\bar{1}\bar{1}$, $11\bar{1}$, $\bar{1}11$, $\bar{1}\bar{1}1$, $\bar{1}\bar{1}\bar{1}$, $\bar{1}1\bar{1}$. The bar on the top of the index figure indicates the corresponding faces have cut the axis concerned, at its negative end. A face intersecting the positive side of an axis is indicated by the corresponding index figure only.

Returning to the matter of the intercepts made by a face on the crystallographic axes, shows two faces ABC and ABE, cutting all the three axes. The intercept OA, OB and OC are the same, but OE is half this distance.

For the face ABC, the ratio of intercepts is

$$\frac{OA}{1} : \frac{OB}{1} : \frac{OC}{1} \quad \text{or} \quad \frac{a}{1} : \frac{b}{1} : \frac{c}{1}$$

and for face ABE

$$\frac{OA}{1} : \frac{OB}{1} : \frac{OE}{1} : \quad \text{or} \quad \frac{a}{1} : \frac{b}{1} : \frac{c}{1}$$

According to the Millerean system of notation proposed by W. H. Miller in 1839 and now generally adopted, the face ABE as 112. The indices for each face are thus inversely proportional to the intercepts made on the crystallographic axes. The face ABC is called the parameteral plane as the parameters of its intercepts are unity (J. F. Kirkalday).

*The Law of Rational Ratios of Intercepts :** The index of a face parallel to an axis is O, for any quantity divided by infinity is zero. Thus a face with intercepts 2a. ∞ b, c will have ratio

$$\frac{a}{2a} : \frac{b}{\infty b} : \frac{c}{c}$$

and indices -02. The indices of a face are usually enclosed in round *brackets* e.g. (102), whist a bar over a figure means that the face cuts that axis on its negative side. The position of a face in relation to all the crystallographic axis is, therefore, precisely stated by the method of notation.

If we place a face cutting the *a* axis of the holo-symmetric class of the cubic system and parallel to the other two axes, that is a face with indices (100), then as this class has a vertical axis of fourfold symmetry, there must be corresponding faces with indices ($\bar{1}00$), and (010) and ($0\bar{1}0$), whist faces (001) and ($00\bar{1}$) are required to satisfy the horizontal axes as regards their symmetry, make up a form. Similarly, if the axes are cubic, then the (111) face must be balanced by the faces ($\bar{1}11$), ($1\bar{1}1$), ($\bar{1}\bar{1}1$) to satisfy the tetrad vertical axis of symmetry and by the faccs ($\bar{1}11$), ($1\bar{1}1$), ($\bar{1}\bar{1}1$), and ($\bar{1}\bar{1}\bar{1}$) to satisfy the horizontal plane of symmetry, making up the eight faces of another form, the octahedron.

Forms may be either *closed,* enclosing a space, as in the cube or octahedron, or they may be *open* forms, which can only enclose a space if they are combined with one or more other forms, as in basal pinacoid and hexagonal prism (J. F. Kirkalday).

CLASSIFICATION OF CRYSTALS

Crystals have been divided into six systems comprising of thirty two classes. Each of these is defined by a combination of symmetry elements unique to it. Each one of the six crystal systems has got a number of classes differing among themselves in their symmetry. In every system, the class having the maximum or highest symmetry is known as the *normal class or holosymmetric or holohedral* and its symmetry is the standard for the system while the other classes are lower in degree of symmetry.*

The Crystal Systems

Systems	Axes	Symmetry	Type	Common minerals of the type
I. Isometric (Cubic	three equal axes. a, a, a, at right angles to one another.	9 planes, 13 axes ($3Ax_4$, $4Ax_3$, $6Ax_2$), a Centre.	Galena (Normal class)	Galena, Garnet, Diomond Magnetite
		3 planes, 7 axes ($3Ax_2$, $4Ax_3$), a Centre	Pyrite	Pyrite, Cobaltite.
		6 planes, 7 axes ($3Ax_2$, $1Ax_3$), no Centre.	Tetrahedrite	Tetrahedrite, Zinc blende,
II. Tetragonal	three axes, a, a, c, at right angles, two equal horizontal, one vertical axis longer or shorter than others.	5 planes, 5 axes ($4Ax_2$, $1Ax_4$). a Centre.	Zircon	Zircon, Rutile, Cassiterite

System	Axes	Symmetry	Type	Mineral
III. Hexagonal	four axes, a. a, a, c, three equal horizontal at 120° angles with each other and one vertical axis at right angles to the plane containing the horizontal axes.	7 planes of Symmetry. 7 axes ($6Ax_2$, $1Ax_4$), a Centre	Beryl	Beryl
		3 planes, 4 axes ($3Ax_2$, $1Ax_3$), a Centre	Calcite	Calcite, Siderite, Corundum, Hematite
		3 planes, I axes ($1Ax_3$), no Centre	Tourmaline	Tourmaline
		no planes, 4 axes ($3Ax_2$, $1Ax_3$), no Centre	Quartz	Quartz Cinnabar
IV. Orthorhombic	three unequal axes, a, b, c, at right angles	3 planes, 3 axes ($3Ax_2$), a Centre	Barytes	Barytes, Olivine, Topaz, Sulphur
V. Monoclinic	three unequal axes, a, b, c, one vertical, one at right angles to the vertical axis, the third making as oblique angle with the plane containing two	1 plane, 1 axes ($1Ax_2$), a Centre	Gypsum	Gypsum, Orthoclase, Augite, Muscovite, Hornblende
VI. Triclinic	three unequal axes, a, b, c, none at right angles	no planes, no axes, a Centre	Axinite	Barytes, Oli-, Axinite, Kyanite

* Ax for axis of Symmetry. Number before symbol gives number of planes or axes of Symmetry present.

CRYSTALLOGRAPHIC PROJECTION

The term *crystallographic projection* is used for any representation of a cystal. Since the crystallographer is mainly concerned with the angular relationships of the crystal faces, it is possible to dispense with a pictorial representation and use a purely geometrical projection. All projections in common use involve the projection of nor mals to the crystal faces on to a sphere. In a *horizontal projection*

of a crystal, the ~~crystal lies on~~ the basal plane or more generally the plane normal to the prismatic zone are used. This gives, in fact, a map of the crystal as viewed from above looking the direction of the axis of the prismatic zone. The *spherical projection* can be reduced to a two dimensional representation by the use of the same methods as are used in map projections for reducing the Earth's sphere to a flat map. In making a spherical projection of a crystal, it is assumed that the crystal lies within a sphere, the centre of which coincides with the centre of the crystal. From this common centre, normals are drawn to the successive faces of the crystal and continued until they meet the surface of the sphere. The points at which these normals touch that surface locate the poles of the respective faces and together form the spherical projection of the crystal (after Dana & Ford).

Of the projections the most useful in crystallography are:

1. Orthographic Projection
2. Clinographic Projection
3. Stereographic Projection
4. Gnomonic Projection

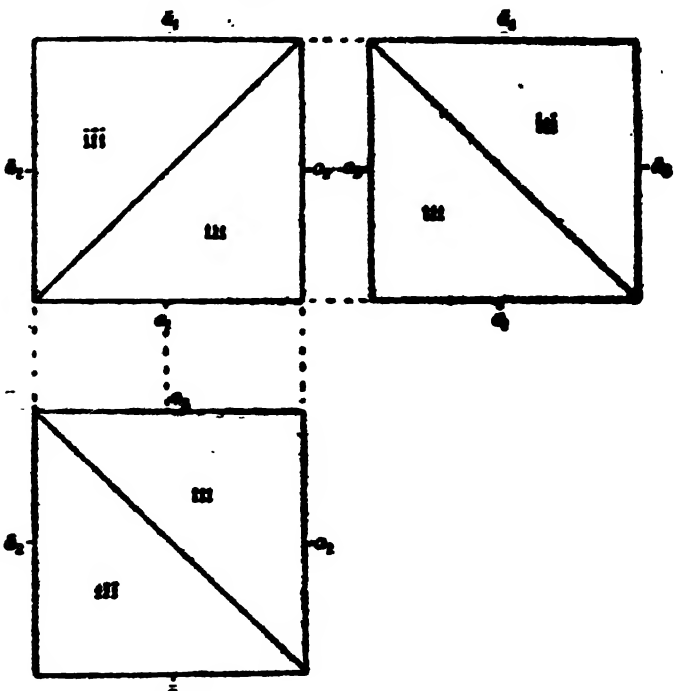


Fig. 12A. Orthographic projection of an Isometric Crystal

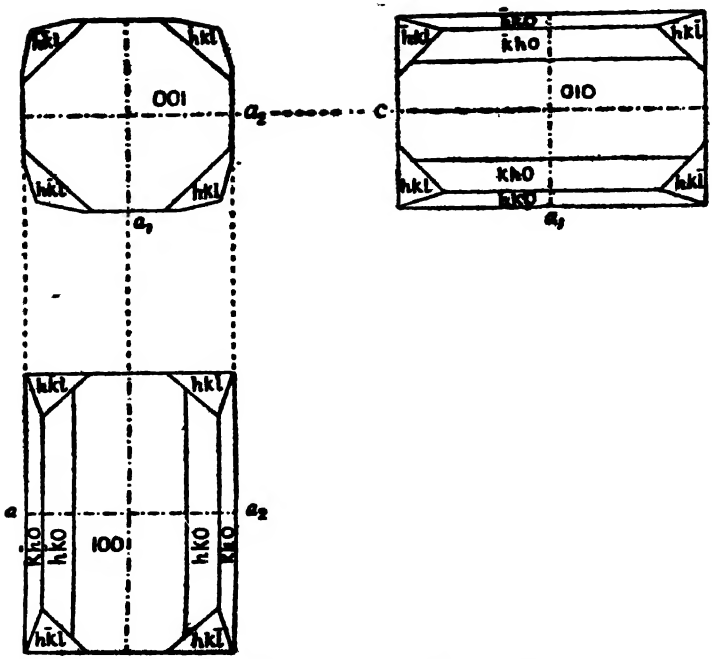
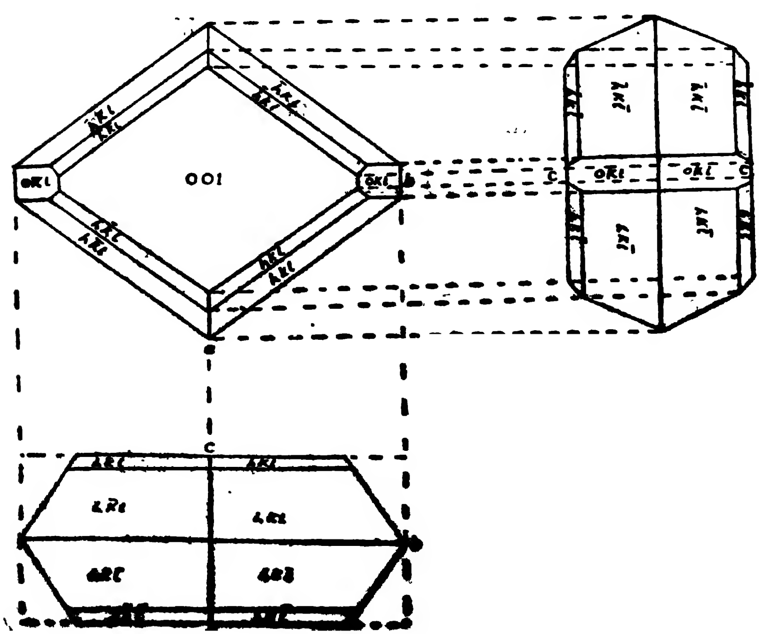


Fig. 12B. Orthographic projection of a Tetragonal Crystal



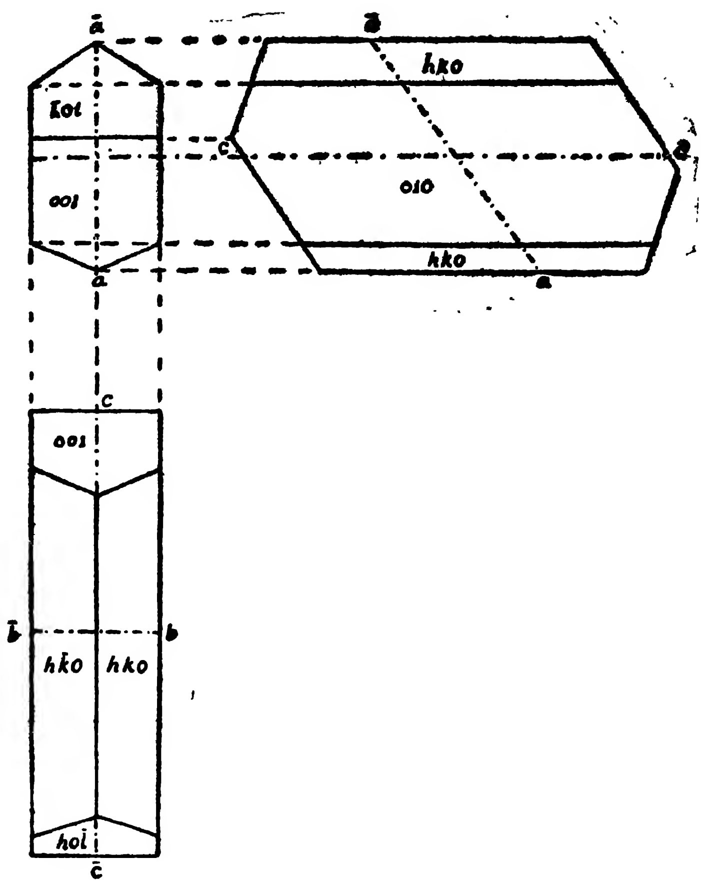


Fig. 12D. Orthographic projection of a Monoclinic Crystal

Orthographic Projection

This is a way of representing crystals on paper. The drawing is on three mutually perpendicular planes, if possible, parallel to principal crystallographic planes. The faces are projected by means of lines perpendicular to these planes; they give an idealised view of the crystal as it would look from an infinite distance.

The orthographic projection is, in effect, a-'plan' on map. The three figures, known in crystallography as the a-plan, b-plan and

c-plan, correspond to the front, side and top views or to the elevation, section and plan views respectively.

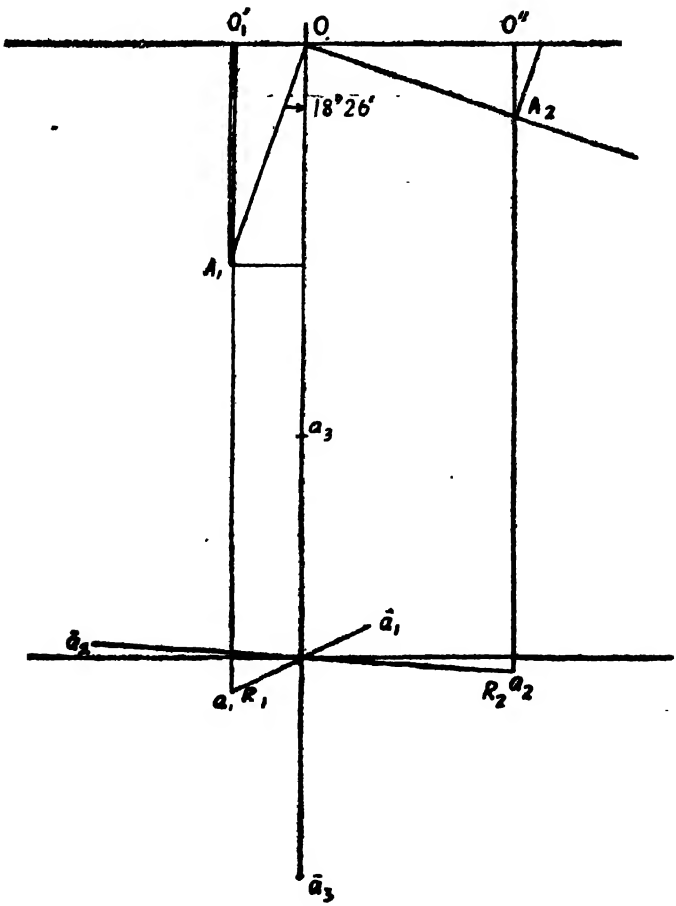


Fig. 13. Development of Crystallographic axes for isometric system

Clinographic Projection

This is a method of 'block' drawing for representing the three dimensional aspect of crystals as they actually look. The projection is similar to perspective drawing except for the fact that all parallel lines are parallel in the drawing. The conventional position for drawing the crystal is close to the 'reading position'—as if looking down into an octohedral face.

The axial cross in drawn by a geometrical construction; the angle of view is taken at $\tan^{-1} /3$ because the tangent of that angle is (1/3) and this controlling factor is a simple fraction, and the angle is low. The construction is given below.

The a_3 axis is first drawn by drawing a vertical line 3″ long. This is then produced upwards and a point O is chosen on it. From O, a line OA'_1 making an angle of 18°26′ ($\tan^{1} 1/3$) with the vertical is drawn and made of semiaxial length. Then OA_2 is drawn –x′y′. Through O, XOY is drawn ⊥ to the a_3 axis. The vertical line through A_1 is drawn to intersect xy by a length ½OO′. This gives the point R_1 which is the+ve and of a_1 axis. R_1 is joined to the mid-point of a_3 and produced beyond by an equal amount. The vertical through A_2 is drawn to cut xy at O″ and A_2e is drawn perpendicular to DA_2 to cut XY at e. $O''A_2$ is produced downward beyond X′Y′ by an amount 1/2 O″e. This gives R_2, the positive end of the a_2 axis. This is joined to the mid-point of a_3 and produced beyond to an equal length to give the axis a_2. Thus the crystallographic axes for the isometric system are drawn in the clinographic projection.

Stereographic Projection

The Stereographic projection is derived from the spherical projection. The crystal is considered to be within a sphere by the points where normals to these faces passing through the central, intersect the sphere. Thus the spherical projection is angle-true. From it the points are projected on to an equatorial plane to give the stereographic projection; this projection is achieved by taking one half of the sphere, and joining all points to the opposite pole. The intercept of these joints on the equatorial plane gives the points on the stereographic projection. The equatorial circle is undistarted and is known as the 'primitive'. In crystallography, the crystal is oriented with its *c*–axis vertical, its positive and upward–the standard reading position–and the upper hemisphere is used for projection.

Great-circles are intercepts of planes passing through the centre, on the surface of the sphere. Thus all zone-planes, i.e., normals to zones axes appear as great circles on the sphere, since all planes are considered to pass through the centre. All crystal planes can also be drawn as great circles but this is not common practice, and the planes are represented by their poles. A great circle on the stereographic projection appears as a circular arc intersecting the primitive at the extremities of a diameter, or as straight lines.

A small circle is a circle formed by the intersection of any plane not passing through the centre or of a cone passing through the

centre on the sphere. The small circles also appear as circular arcs on the 'stereogram'.

Faces are plotted using angular relations and zonal relations between them. The procedure is given below for all crystal systems except monoclinic and triclinic.

1. The c axis being vertical (a_3 in isometric) is plotted at the diametrically opposite east-west points and joined by a line. The a (a_1 in isometric and hexagonal) is plotted on the north-south axis. In the hexagonal system, a and a_2 axes are plotted at this appropriate angular distances from a_2.

2. All faces parallel to 'c' will have their poles on the primitive, the paints being determined by their angles with a and b. Thus 100 will be at the pole of a, and 010 at b. The other faces in the hko zone will be at the angles subtended at the centre from these.

3. Faces of the hol type will be on the a axis, and those of the okl type on the b axis. Their plotting is according to their angles with the pinacoids. The zones are not in the horizontal plane and necessitate special construction. The plane of great circles zone (i.e. 001—010 or 001—100) is taken separately. Now, the zone is the

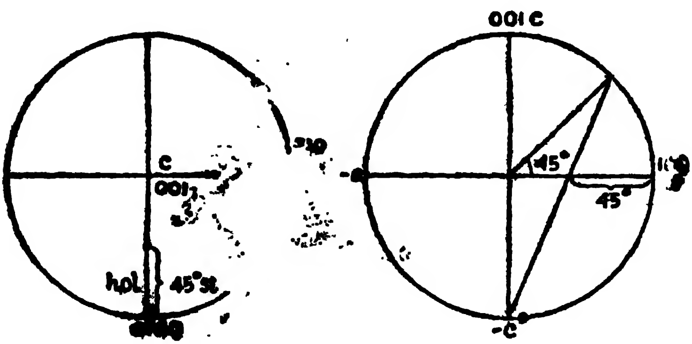


Fig. 14. Auxiliary Circle Construction

projection of a great circle on the sphere passing through both the upper and lower poles. The circle is drawn and is known as the auxiliary circles. The upper pole is at 001, the right hand and of the horizontal line (intercept of primitive) is either 010 or 100. Suppose a face hol makes an angle of 45° with 100. Then on the auxiliary circle, its normal is drawn at that angle from a i.e., the normal of 100. The intercept of this line on the circle is taken and joined on the lower pole (-c) and the intercept of the join on the primitive gives the distance from 100 of a point with that angular distance. This is then transferred to the main diagram. These con-

structions are made on zones 001—010, 001—100, 001—110, etc, and are very useful in giving a variety of dome and pyramidal face-poles.

The auxiliary circle construction is applicable to plotting of poles on any straight zone, e.g., on the zone 110—001 the pole of 111 can be plotted from its angles with either 110 or 001 by an auxiliary circle.

4. Faces of hkl type are plotted using zonal and angular relations. For instance, if a pole of hko is obtainable then an auxiliary circle will suffice. However, zone-intersections give prominent poles of this type. Thus, zones 010—101, 100—011, and 001—110, all intersect in the pole of 111. There is a simple method of testing whether a face is 'cozonal' with two other faces. The indices of any two are written down and added or subtracted (either as such or as their multiple), keeping in mind that these are not three digit numbers but three distinct indices; in these operations the index of one face will add or subtract to the a-index of another and so on. If by such addition the indices of the third face can be derived, the three are cozonal,

e.g. 110
111

221—Cozonal with 110 & 111
—222 (i.e. 111 doubled)

—001, or 001, Cozonal with all these.

If a face has been shown to lie on two seperate zones, then the intercepts of these will give the face pole.

Great circle zones are circular arcs. They are drawn as such, the centre being determined by a geometric construction as follows: the diameter of primitive emerging at the extremities of the zone-circle (this is usually known) is taken and a perpendicular to it drawn through the centre of the primitive. The centre lies on this line and can be determined by joining any two poles on the zone and drawing the perpendicular bisector of the join; the intercept gives the centre. If only three cozonal points are known (not the intercepts of circle and primitive) then these are taken in two sets and the intercept of the perpendicular bisectors of their *joints* is the centre of the great circle arc.

5. Some face-plots necessitate small circle constructions. These are used when the angle of a face with known faces or the angle with one and a great circle are known. These are also used to lay off angles on curved-great-circle zones. Small circle constructions are of two types which may be called 2-point and 3-point circles. Small

circles drawn around poles give the locus of points having a fixed angular relation to it. Three point circles are constructed about points on the primitive and two points circles around any point within it.

(i) *Three points circle :*

To draw a small circle of angular radius 30° around the pole of 110 on the stereogram given 110 lies on the primitive. To draw a 30° small circle, it is sufficient to locate three points at 30° from 110. The straight line 001. 110 is drawn and two lines at 30° to it through 001 drawn to intersect the primitive to give two of these points. The third is located on the 001—110 zone by an auxiliary circle construction. Then a circle is drawn through these three points; the centre will be on 001—110 (extended if necessary).

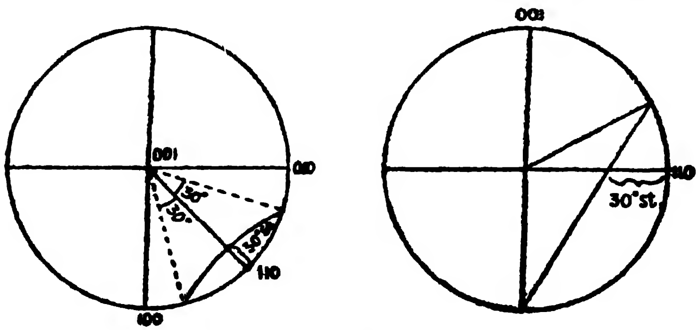


Fig. 15 Three point Circle

(ii) *Two points circle :*

To draw a small circle of radius 30° about a face-pole hkl. On the straight zone 001—hkl—hko two points at 30° from hkl

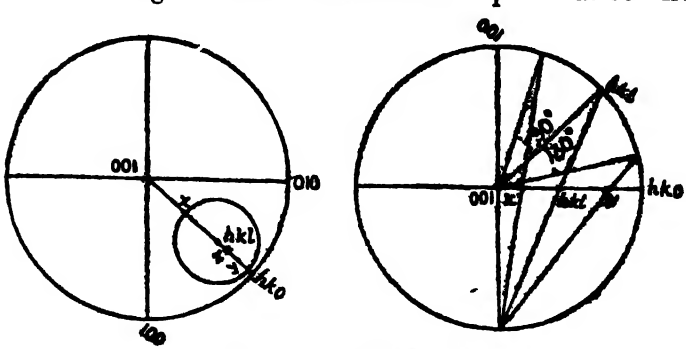


Fig. 16. Two point Circle

and on either side are located using the auxiliary circle. (The pole of hkl is on the horizontal; it is joined to the lower pole and extended to meet the upper semi-circle, and the intercept joined to the centre and line at 30° to radius drawn to give normals to poles at 30° to hkl). These are transferred to the original diagram and are used as ends of a diameter to draw a circle. It will be seen that hkl, although the angular centre of this circle, is not the geometric centre on the projection.

(iii) Small circles around 001 are drawn by measuring off the angle on any straight zone and using it as radius, drawing a circle with 001 as centre.

Using a construction of these techniques, it is possible to locate face-poles from angular and zonal data.

Gnomonic Projection

The Gnomonic Projection is a modification of the stereographic projection and the characters of the gnomonic projection can be understood by considering it to be derived from the spherical projection. This projection is used for higher studies in crystallography. The plane of projection is taken as the horizontal plane which is placed tangent to the north pole of the sphere of the spherical projection. Imaginary straight lines are taken from the centre of the sphere through the face poles that lie on its surface are extended until they intersect the tangential plane on which the gnomonic projection of a crystal is obtained.

Examples

1. Draw a stereogram of the Isometric combination of forms a (100), d (110), o (111). Note briefly procedure.

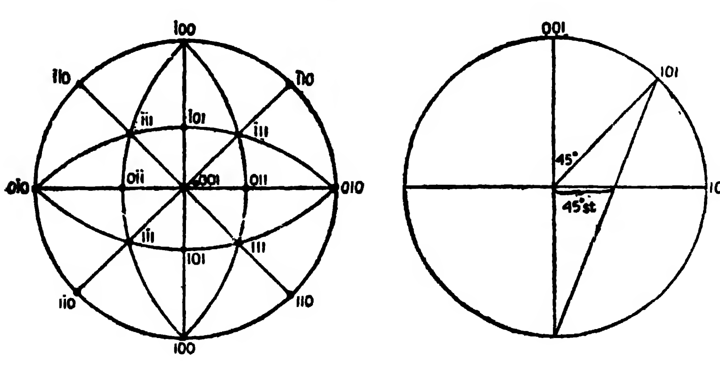


Fig. 17(a).

2. An Orthorbombic crystal shows the following forms—(100), (111), (011), (110). Given the following interfacial angles.

$$011 \wedge 0\bar{1}1 = 60°14'$$
$$110 \wedge 1\bar{1}0 = 50°21'$$

Draw a stereogram of the crystal leaving traces of construction and give explanatory notes on procedure.

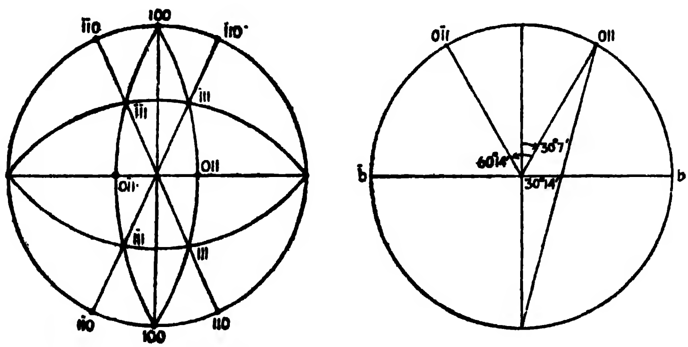


Fig. 17(b).

3. Find the aerial ratio of an Orthorhombic crystal which has (100), (111), (011) developed given

$$110 \wedge 1\bar{1}0 = 50°21'$$
$$011 \wedge 0\bar{1}1 = 60°41'$$

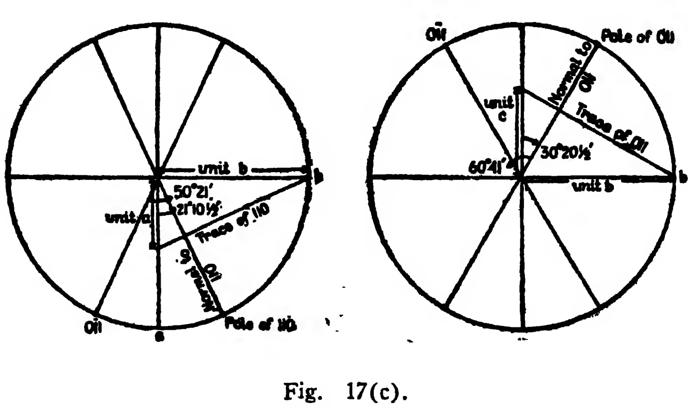


Fig. 17(c).

DESCRIPTIVE CRYSTALLOGRAPHY

ISOMETRIC (CUBIC) SYSTEM

The isometric system (Cubic System) includes all the forms which are referred to three axes of equal length which intersect at right angles. The three axes are interchangeable and they are all designated by a. When a crystal properly oriented, one axis, called a_3, is vertical, another axes a_2, runs right to left and the third axes runs front to back. The positive and negative ends of each axis are shown in the Fig. 17a.

There are five symmetry classes belonging to the Isometric System. They are

1. Normal class. 2. Pyritohedral class. 3. Tetrahedral class. 4. Plagiohedral class. 5. Tetartohedral class.

1. *Normal class : Galena type*

Galena type takes its name from the mineral Galena, which belongs to the isometric system. This type belongs to the *normal class* of the system. The *symmetry* of the Galena type are as follows :

9 Planes of symmetry $\begin{cases} \text{3 axial} \\ \text{6 diagonal} \end{cases}$

13 Axes of symmetry $\begin{cases} \text{Three 4-fold axes} \\ \text{Four 3-fold axes} \\ \text{Six 2-fold axes} \end{cases}$ thirteen

1 Centre of symmetry

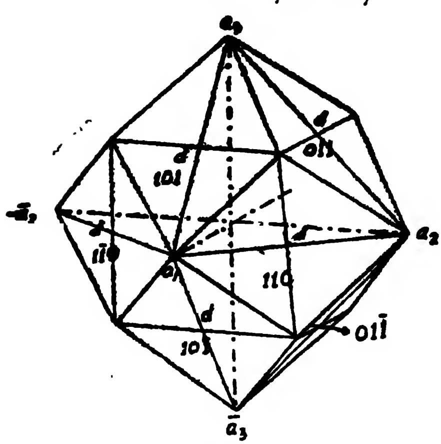


Fig. 18(a). Dodocahedron

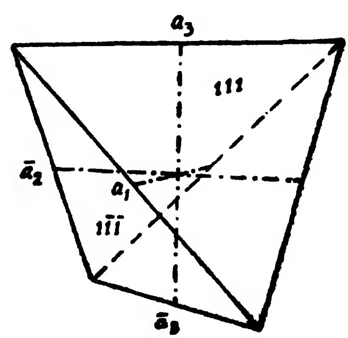


Fig. 18(b). Tetrahedron.

Forms : (i) *Cube* : The cube has the general symbol (100). It is bounded by six similar faces which cut one axis and are parallel to the other two.

(ii) *Octahedron :* The octahedron has the general symbol (111). It is bounded by eight similar faces, each face meeting all three axes at equal distances.

(iii) *Dodecahedron or Rhombdodecahedron :* The dodecahedron has the general symbol (110). It is bounded by twelve faces, each of which meets two axes at equal distances and is parallel to the third.

(iv) *Tetrahexahedron :* The general symbol of the form is (hko) and common forms are (210), etc. It is bounded by twenty-four faces, each face is an isosceles triangle.

(v) *Trisoctahedron :* The general symbol of the form is (hkl) and common forms are (221), etc. It is bounded by twenty four faces, each face is an isosceles triangle.

(vi) *Trapezohedron :* The general symbol of the form is (hll) and a common form is (211). It is bounded by twenty four like faces, each face a trapezoid.

(vii) *Hexoctahedron :* The general symbol of the form is (hkl) and a common form is (321). It is bounded by fortyeight like faces, each face a scalena triangle.

Mineral Examples : Some common Galena type minerals are Galena, Diamond, Magnetite, Garnet, Flour-spar, Spinel, Leucite and Analcite.

2. *Pyritohedral class : Pyrite type*

Pyrite type takes its name from the mineral Pyrite, which belongs to the isometric system. This type belongs to Pyritohedral class of the system. The symmetry of the Pyrite type are as follows :

3	Planes of symmetry —	axial
7	Axes of symmetry	three 2-fold axes four 3-fold axes

A Centre of symmetry

Forms : (i) Cube (100), (ii) Dodecahedron (110), (iii) Octahedron (111), (iv) Pyritohedron (210) etc., (v) Trisoctahedron (221), etc. (vi) Trapezohedron (211) etc. (vii) Diploid(321), etc.

Mineral Examples : Some common Pyrite type minerals are Pyrite, Cobaltite, Smaltite and Choanthite.

3. *Tetrahedral class : Tetrahedrite type*

Tetrahedrite type takes its name from the mineral Tetrahedrite, which belongs to the isometric system. This type belongs to Tetra-

hedral class of the system. The symmetry of Tetrahedrite type are as follows:

6 Planes of symmetry — diagonal

7 Axes of symmetry $\begin{cases} \text{three 2-fold axes} \\ \text{four 3-fold axes} \end{cases}$ Seven

No Centre of symmetry

Forms: (i) Cube (100); (ii) Dodechedron (110); (iii) Tetrahedron (111); (iv) Tetrahexahedron (210) (v) Deltoid dodecahedron (221), etc.; (vi) Tristetrahedron (211), etc.; (vii) Hexatetrahedron (321) etc.

Mineral Examples: Tetrahedrite, Zinc Blende, Boracite.

Plagiohedral class : Cuprite type

The Symmetry of the Cuprite type are as follows:

No Planes of symmetry
13 Axes of symmetry
No Centre of symmetry

Tetratohedral class : Ullmannite type

The Symmetry of Ullmannite type are as follows:

No Planes of symmetry
7 Axes of symmetry
A Centre of symmetry

TETRAGONAL SYSTEM

The Tetragonal System includes all the forms which are referred to three axes at right angles to each other of which the two horizontal crystallographic axes are equal in length and a third vertical axis which is either shorter or longer than the other two. The two horizontal axes are equal in length and are interchangeable.

The horizontal axes are denoted by the letter a and the vertical axis by c. When a crystal is properly oriented, one axis c is vertical, a_1 runs front to back and the third axis a_2 runs right to left.

There are seven symmetry classes belonging to the Tetragonal System. They are:

1. Normal class, 2. Hemimorphic class, 3. Tripyramidal class, 4. Pyramidal—Hemimorphic class, 5. Sphenoidal class, 6. Trapezohedral class, 7. Tetratohedral class.

1. *Normal class : Zircon type*

Zircon type takes its name from the mineral Zircon, which belongs to the Tetragonal System. This type belongs to the normal

class of the system. The symmetry of the zircon type are as follows :

5 Planes of symmetry $\begin{cases} \text{3 axial} \\ \text{2 diagonal} \end{cases}$

5 Axes of symmetry $\begin{cases} \text{Four 2-fold axes} \\ \text{One 4-fold axes} \end{cases}$

A Centre of symmetry

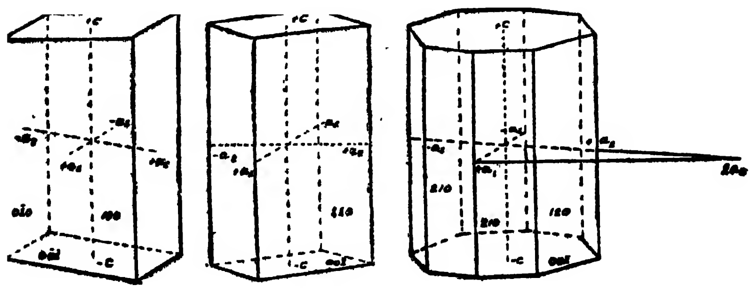


Fig. 19(A). A. Prism of 2nd Order and Basal Pinacoid, B. Prism of Ist Order and Basal Pinnacoid. C. Dihexagonal Prism.

Forms : (i) Basal Pinacoid (001); (ii) Tetragonal Prism of the Second order (100), (010). (iii) Tetragonal Prism of First order (110); (iv) Ditetragonal Prism (210); (v) Tetragonal Pyramid of the Second order (101), (001); (vi) Tetragonal Pyramid of the First order (111); (vii) Ditetragonal Pyramid (212), (211).

Mineral Examples : Zircon, Rutile, Cassiterite etc. are the commonest minerals crystallising in the Zircon Type of the Tetragonal System.

Forms :

(i) *Basal Pinacoid :* The basal pinacoid or base is an open form which includes two similar faces which are parallel to the two horizontal axes a_1 and a_2 and each face intersecting the vertical axis c. Its symbol is 001 for the upper face and 001 for the lower face.

(ii) *Prism of First Order :* The prisms of the first order includes four faces, the symbols of the four faces are 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$. Each face intersects the two horizontal axes at equal distances.

(iii) *Prism of Second order :* The prism of the second order includes four faces, the symbols of the four faces are 100, 010, $0\bar{1}0$. The general symbol is 100. The faces are parallel to the vertical and to a horizontal axis.

(iv) *Ditetragonal Prism :* The ditetragonal prism is an open form of eight similar faces, each face is parallel to the vertical axis

while cutting the two horizontal axes at unequal distances. The general symbol is hko, e.g., the symbol of the faces is 210.

(v) *Pyramid of First order:* A pyramid of the first order is a form of eight similar faces cuts the two horizontal axes at equal distances and also cut the vertical axis. The general symbol is hhl and the symbol of the form is 111.

(vi) *Pyramid of the Second order:* The pyramid of the second order is the form which consists of a square pyramid with eight isosceles faces. The faces of the pyramid are parallel to one of the horizontal axes and cuts the vertical axis and one of the horizontal axes. The general symbol is hol and the symbol of the form is 101.

(vii) *Ditetragonal Pyramid:* The ditetragonal pyramid is a double eight sided pyramid, has sixteen similar faces which meet the three axes at unequal distances. The general symbol is hkl and the symbol of the form is 211.

Mineral Examples: The commonest minerals crystallising in the Zircon type of Tetragonal system are Zircon, Cassiterite, rutile, etc.

HEXAGONAL SYSTEM

The hexagonal system includes all the crystal forms which are referred to four axes, three equal horizontal axes making angles of 120° with each other and a vertical axis at right angles to them. The three horizontal axes are denoted by the letters a_1, a_2, a_3 and the vertical axis by c. The positive and negative ends of each axis are shown in the Fig. 19 (A).

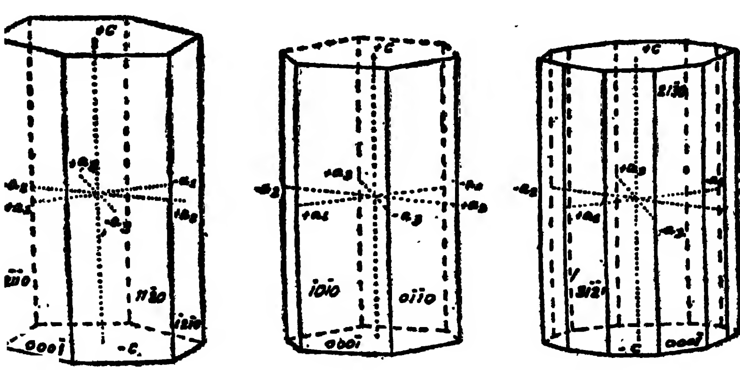


FIG. 19A+B

Fig. 19(B). A. Hexagonal Second order pyramid. B. Hexagonal First order pyramid. C. Dihexagonal pyramid.

There are twelve symmetry classes belonging to the Hexagonal System. There are two divisions of the system.

Hexagonal Division :

1. Normal class, 2. Hemimorphic class, 3. Tripyramidal class, 4. Pyramidal–Hemimorphic class, 5. Trapezphedral class, 6. Trigonal class, 7. Tetratohedral class, 8. Rhombohedral class, 9. Rhombohedral–Hemimorphic class, 10. Tri-rhombihedral class, 11. Trapezohedral class, 12. Trigonal Tetratohedral Hemimorphic.

1. *Normal class : Beryl type*

Beryl type takes its name from the mineral Beryl, which belongs to the Hexagonal System. This type belongs to the normal hexagonal type of symmetry. This symmetry of the Beryl type are as follows :

7 Planes of symmetry { 4 Axial, 3 Diogonal

7 Axes of symmetry: Six 2-fold axis, One 6-fold axes

A centre of symmetry

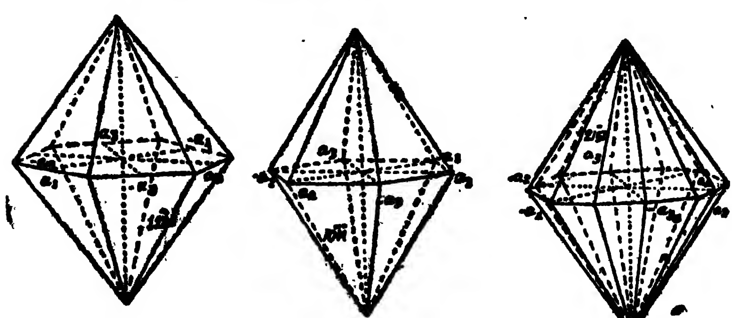


Fig. 20A. A. Hexagonal Second order pyramid, B, Hexagonal First order pyramid. C. Dihexagonal pyramid.

Forms :

(i) ***Basal Pinacoid :*** The base or basal pinacoid is an open form of two faces and each of which intersect the vertical axis and are parallel to the three horizontal axes. The symbol of the faces are 0001 and $000\bar{1}$.

(ii) ***Prism of the First Order :*** The prism of the first order is an open form of six faces. Each face is parallel to the vertical axis and meets two horizontal axes at equal distances. The symbols of the form are $10\bar{1}0$, $01\bar{1}0$, $\bar{1}100$, $\bar{1}010$, $0\bar{1}10$, $1\bar{1}00$.

(iii) *Prism of the Second Order:* The prism of the Second order is an open form of six faces. Each face is parallel to the vertical axis and meets three horizontal axes, one axis at the unit distance and the other two axes at twice the distance. The symbols of the six faces are $11\bar{2}0$, $\bar{1}1\bar{1}0$, $\bar{1}2\bar{1}0$, $\bar{2}110$, $\bar{1}\bar{1}20$, $1\bar{2}10$, $2\bar{1}\bar{1}0$.

(iv) *Dihexagonal Prism:* The dihexagonal prism is an open form which has twelve faces. Each face is parallel to the vertical axis and meets the three horizontal axes at different lengths. The general symbol is $hi\bar{k}o$ and the symbol of the form is $21\bar{3}0$.

(v) *Pyramid of the First Order:* The pyramid of the first order is a closed form bounded by twelve similar faces, each face intersects two horizontal axes at equal distances and is parallel to the other two horizontal axes and also intersects the vertical axis. The general symbol of the form is $ho\bar{k}l$ and symbol of the face is $10\bar{1}1$.

(vi) *Pyramid of the Second Order:* The pyramid of the second order is a closed form of twelve faces which intersect the vertical axis and three horizontal axes one at the unit distance and other two at twice the distance. The general symbol is hh2hl and symbol of form is $11\bar{2}1$, $11\bar{2}2$, 2243.

(vii) *Dihexagonal Pyramid:* The dihexagonal pyramid is bounded by twenty four similar faces. Each face meets the vertical axis and the horizontal axes at unequal distances. The general symbol is $\bar{h}ikl$ and the symbol of the form is $21\bar{3}1$.

Forms: (i) Basal Pinacoid (0001); (ii) Hexagonal Prism of the Second Order $(11\bar{2}0)$; (iii) Hexagonal Prism of the First Order $(10\bar{1}0)$; (iv) Dihexagonal Prism $(21\bar{3}0)$, etc. (v) Hexagonal Pyramid of the Second Order $(11\bar{2}1)$ etc. (vi) Hexagonal Pyramid of the First Order $(10\bar{1}1)$, etc. (vii) Dihexagonal Pyramid $(21\bar{3}1)$, etc.

Mineral Examples: Beryl.

Trapezohedral Class : Quartz Type

The symmetry of the quartz type are as follows:

No Planes of symmety

4 Axes of symmetry { Three 2-fold axes
One 3-fold axes

No centre of symmetry

Forms: (i) Basal Pinacoid (0001); (ii) Trigonal Prism of the Second Order $(11\bar{2}0)$; (iii) Hexagonal Prism of the First Order $10\bar{1}0)$; (iv) Ditrigonal Prism $(21\bar{3}0)$, etc. (v) Trigonal Pyramid $(11\bar{2}1)$, etc. (vi) Rhombohedron $(10\bar{1}1)$, etc. (vii) Trigonal Trapezohedron $21\bar{3}1$ etc.

Mineral Examples: Quartz, Cinnabar are the commonest minerals crystallising in the Quartz Type of the Hexagonal System.

Rhombohedral Class : Calcite Type

The symmetry of the Calcite type are as follows:

3 Planes of symmetry digonal

4 Axes of symmetry { three 2-fold axes; one 3-fold axes

A centre of symmetry

Forms: (i) Basal Pinacoid (0001); (ii) Hexagonal Prism of the Second Order ($11\bar{2}0$) (iii) Hexagonal Prism of the First Order ($10\bar{1}0$);- (iv) Dihexagonal Prism (2130), etc. (v) Hexagonal Pyramid of the Second order (1121), etc.; (vi) Rhombohedron (1011), etc.; (vii) Scalenohedron ($21\bar{3}1$), etc.

Minerals Examples: Calcite, Siderite, Corundum, Hematite are the commonest minerals crystallising in the Calcite Type.

Rhombohedral-Hemimorphic Class : Tourmaline Type

The Symmetry of the Tourmaline Type are as follows:

3 Planes of symmetry—diagonal

1 Axes of symmetry—one 3-fold axes

No centre of symmetry

Forms: (i) Basal Planes (0001) ard (0001); (ii) Hexagonal Prism of the Second order (1120); (iii) Trigonal Prism of the First order ($10\bar{1}0$); (iv) Ditrigonal Prism ($21\bar{3}0$), etc. (v) Hemimorphic Hexagonal Pyramid ($11\bar{2}1$), etc. (iv) Trigonal Pyramid or Hemi-scalenohedron ($21\bar{3}\bar{1}$), etc.

Mineral Examples: Tourmaline.

ORTHORHOMBIC SYSTEM

The Orthorhombic system includes all the crystal forms which are referred to three unequal to three axes at right angles and all the axes are of different lengths. The shorter horizontal axis, the brachy axis, is denoted by *a*, which runs front to back and the longer horizontal axis, the macro axis, is designated by *b*, which runs right to left. The vertical axis is *c*.

Normal Class : Baryte Type

Baryte Type takes its name from the mineral Baryte, belongs to the Orthorhombic system. This type belongs to the normal class and only are important symmetry class of the system.

There are two symmetry classes belonging to the Orthorhombic system. They are (i) Normal class, (iii) Sphenoidal class.

The symmetry of the Baryte type are as follows:

3 Planes of symmetry axial

3 Axes of symmetry three 2-fold axes

A centre of symmetry

Forms :

(i) *Basal Pinacoid :* The base or basal pinacoid is an open form of two faces parallel to the plane of horizontal axes and the symbols of the two faces are 001 above and $0\bar{1}0$ below. This form is denoted by the letter *c* and it is also called *c*-pinacoid.

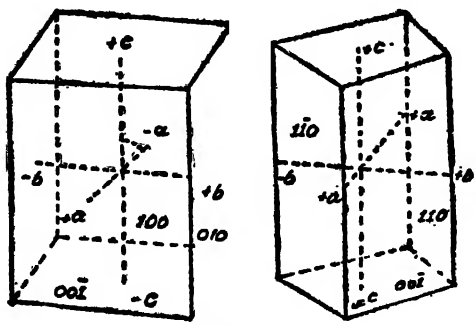


Fig. 20B.

A. Three pinacoids B. Basal Pinacoid and unit prism.

(ii) *Macropinacoid :* The macropinacoid includes two faces, and each of which is parallel to the macro axis as well as the vertical axis. The symbols of the two faces are 100 front and 100 back. This form is denoted by the letter *b* and it is also called *c*-pinacoid.

(iii) *Brachypinacoid :* The brachypinacoid has two faces, each of which is parallel both to the brachy axis *a* and the vertical axis *c*. The symbols of the two faces 010 and $0\bar{1}0$ and the form is denoted by the letter *b* ; it is also called *b*-pinacoid.

(iv) *Prism :* A prism includes four faces, the faces of the prism are parallel to the vertical axis and intersect both the horizontal axes. The general symbol is (hkl). The *unit prism* (110) is a form whose faces cuts the horizontal axes at the same relative distances. There are also two types of prisms, namely, macroprisms and brachyprisms. The symbol of the faces of the unit prism are 110, $\bar{1}10$, $\bar{1}\bar{1}0$, $1\bar{1}0$. The symbols of the other prisms are 210, 120, 320, etc.

(v) *Macrodome :* The macrodomes are open forms of four-faces which are parallel to the macro-axis *b*, but cut the vertical axis *c* and the horizontal axis *a*. The general symbol is (hol). The symbol of faces of the macrodome $10\bar{1}$, 101, $\bar{1}0\bar{1}$, $\bar{1}01$. The other macrodomes are (201), (203), (103), etc.

(vi) *Brachydome :* The brachydomes are an open form of four faces which are parallel to the brachy axis *a*, and cut the other two axes *c* and *b*. The general symbol is (*hkl*) and the symbol of the four faces $00\bar{1}$, $0\bar{1}\bar{1}$, 011 and $0\bar{1}1$. The symbols of the other brachydomes are (012), (023), (031), etc.

(vii) *Pyramid :* The pyramids are closed forms of eight faces, each face a scalene triangle. The general symbol is (hkl). The pyramid may be divided into three groups, namely unit pyramid, macropyramid and brachypyramid. The symbol of the unit pyramid is (111), and for other pyramids are (112), (213), (123), etc.

Mineral Example : Baryte, olivine, topaz aragonite, staurolite, andalusite, sulphur, celestite, enstatite, anhydrite, etc. are the commonest minerals crystallising in the Baryte Type of the Orthorhombic system.

MONOCLINIC SYSTEM

The Monoclinic System includes all the crystal forms which can be referred to three unequal axis, two of which are at right angles, having one of their axial inclinations oblique. The axes are denoted by letters *a, b, c.* When a crystal is properly oriented, one axis, called *c* is vertical; the *b* or Ortho-axis is at right angles to the *c* axis, runs right to left; the *a* or clino axis inclined to the plane containing the *c* and *b* axis, runs up and away from the observer. The acute angle between the clino axis *a* and the vertical axis *c* is represented by the letter β ; the angles between clino axis *a* and Ortho-axis *b* and vertical axis *c* are at right angles.

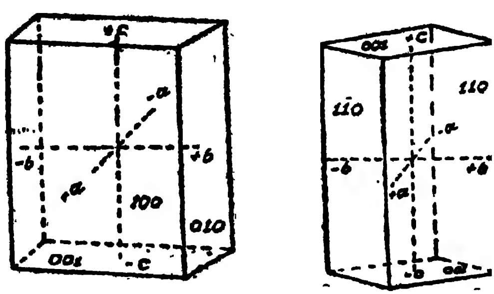


Fig. 21A. Three pinacoids. B. Basal pinacoid and unit prism.

Normal Class : Gypsum Type

Gypsum type takes its name from the mineral Gypsum, which belongs to the monoclinic system. This type belongs to the normal class of the system. The symmetry of the Gypsum type are as follows :

1 Plane of symmetry, containing *a* axis and the *c* axis.
1 Axis of symmetry, the *b* axis.
A centre of symmetry

Forms :

(i) *Basal Pinacoid :* The base or basal pinacoid includes two faces, parallel to the plane of the axis the clino axis *a* and the

Ortho-axis *b* and intersect the vertical axis *c*. The symbol of the upper and lower faces are 001 and 001. The basal pinacoid is denoted by the letter '*c*' and called *c*- pinacoid or *c*- face.

(ii) ***Orthopinacoid:*** The orthopinacoid includes two faces, each face is parallel to the ortho axis *b* and the vertical axis *c*, and intersecting the Clino axis *a*. The symbol of the front face and back face are 100 and 100. The form is denoted by the letter ***b*** and is called *a*-face or *a*-pinacoid.

(iii) *Clinopinacoid:* The Clinopinacoid includes two faces, each face is parallel to the clino-axis *a* and the vertical axis *c*, and intersecting the ortho axis *b*. The symbol of the left and the right faces are 010 and 010. This form is denoted by the letter *b* and is called *b*-face or *b*-pinacoid.

(iv) *Prism:* The Prisms are all of oblique rhombic prism. The prisms may be divided into three classes such as the unit prisms (110), the orthoprisms (hko) and clinoprisms (hko). This form has two faces, each face parallel to the vertical axis *c* intersects the clino axis *a* and ortho axis *b*.

(v) *Orthodomes:* The four faces parallel to the ortho axis b and cuts the clino axis *a* and the vertical axis *c*. This is also called Hemi-orthodomes. They have the indices Ī01 and 101 for positive form and 101 and 101 for negative form. The general symbol are positive (h̄ol) and negative (hol), where h, l = 1 or Ī.

(vi) *Clinodomes:* The clinodomes are the forms whose faces are parallel with the clino axis *a* and intersect the ortho-axis *b* and the vertical axis *c*. The face symbol of the unit clinodome are 001, 0Ī1, 0ĪĪ. 01Ī. The general symbol is (okl). (where k,l.=1 or 1).

(vii) *Pyramids:*. The pyramids includes four faces and these forms are also known as hemi-pyramids. The pyramids are positive if the faces occur in the acute angles and negative, if they occur in the obtuse angles. The general symbol is hkl. They have the indices 111, Ī11. ĪĪ1, 11Ī, 1ĪĪ, where h,k,l = 1 or Ī.

Mineral Examples: Gypsum, Orthoclase, Augite, Hornblende, Muscovite, Biotite, Sphene and Epidote are the common minerals crystallising in the Gypsum Type of Monoclinic System.

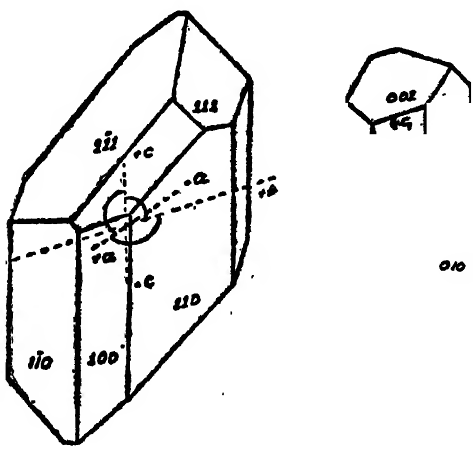
TRICLINIC SYSTEM

The Triclinic System includes all the crystal forms which can be referred to three unequal axes (crystallographic axes) and none is at right angles to another. When a crystal properly oriented, one axis, called *c*, is vertical second axis, called *a*, runs up and away from the observer, third axis, called *b*, *a* axis and *b* axis are also known brachy axis and macro axis. The angle between the axis *c* and *b* is α between *a* and *c* is β and *a* and be is γ.

Normal class : Axinite type

Axinite type belongs to the normal class of the Triclinic System. The symmetry of the Axinite type are as follows:

No Plane of symmetry
No Axis of symmetry
A centre of symmetry



A) B.

Fig. 22A. Axinite : combination of hemi-prisms, macropinacoid, brachypinocoid, hemi-macrodome. B. Albite : Combination of prisms, brachipinacoid, basal pinacoid, macrodome.

Forms :

(i) *Basal Pinacoid :* The base or basal pinacoid or c-pinacoid includes two parallel faces each of which intersecting the vertical axis and lying parallel to the other two axes. The symbol of basal pinacoid is 001.

(ii) *Macropinacoid :* The macropinacoid or a pinacoid includes two parallel faces each face intersecting the brachy axis and lying parallel to the vertical axis and macro axis. The symbol is 100.

(iii) *Brachypinacoid :* The brachypinacoid or *b*-pinacoid includes two parallel faces intersect the macro axis and are parallel to the brachy axis and the vertical axis. The symbol is 010.

(iv) *Prisms :* The Prisms include two parallel faces intersecting the *a* and *b* axes and are parallel to the vertical axis. The symbol is 110, and the general symbol is hko and $h\bar{k}o$.

(v) *Macrodomes:* The macrodomes includes two faces which are parallel to the macro axis and intersect the brachy axis and the vertical axis. The symbol is 101. The general symbol hol and $\bar{h}ol$.

(vi) *Brachydomes:* The brachydomes includes two faces which are parallel to the brachy axis and intersect the macro axis and the vertical axis. The symbol is 001 and the general symbol are okl and $o\bar{k}l$.

(vii) *Pyramids:* The pyramids includes two parallel faces which intersect all three axes. The symbol is 111 and the general are hkl, $\bar{h}kl$, $\bar{h}\bar{k}l$ $h\bar{k}l$.

Mineral Examples: Axinite and Plagioclase feldspar are the commonest minerals crystallising in the Axinite type of Triclinic System.

PHYSICAL PROPERTIES OF CRYSTALS

The physical properties of crystals are of great practical importance and serve as essential diagnostic features.

Cleavage: The Crystals have a tendency to split along certain definite planes. These crystal planes are always parallel to the actual or possible crystal faces and the position of the crystal faces in space can be designated by the same symbols which are used for designating the position of faces. These crystal planes are called the cleavage planes and the property is known as 'cleavage'. The cleavage of a crystal takes place along those crystal planes across which the bonding is weakest.

Hardness: The hardness of crystals are of great practical importance, specially for the abrasive industry. Hardness is also an important diagnostic feature helpful in the recognition of minerals. The hardness of minerals depends on the strength of bonding within the crystals. Diamond is very hard because of the strong homopolar bonds which bind the carbon atoms. Ionic crystals, including the silicates, have in general considerable hardness, except when a type of bonding weaker than ionic is alone present in part of the structure as in the case of talc which has residual bonds between the silicate layers. The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another, or by a knife.

Accurate determinations of the hardness of minerals can be made in various ways, one of the best being by use of an instrument called a *Sclerometer*. The mineral is placed on a movable carriage, with the surface to be experimented upon horizontal; and this is brought in contact with a steel point (or diamond point) fixed on a support above; the weight is then determined which is just sufficient to move the carriage and produce a scratch on the surface of the mineral.

Elasticity: Alteration in the shape of a body, caused by some reason or another, is called deformation.

External mechanical forces applied to a crystal cause deformations which can be plastic or elastic in nature.

If a force P does not exceed a certain limit, the cessation of the action of this force is followed by the disappearance of the deformation. Such a deformation is elastic.

Elasticity is that property of solids by virtue of which they recover their former shape and dimensions when external forces cease to act.

The force P can be increased to a value after which a body will not recover its former dimensions completely, and some deformation will remain. Such a deformation is called permanent or plastic.

THERMAL PROPERTIES OF CRYSTALS

Heat conductivity of crystals was first studied by Senarmont in 1847. Different faces of a crystal or plates cut from it were covered with a thin layer of Wax. Heat was conducted through a wire which was insulated with asbestos to prevent radiant heat from melting the wax. The wire was wrapped in asbestos only its free end in contact with the crystal through a hole in an asbestos sheet.

The wax melted at the point of contact and in most cases the melted area was in the shape of a circle.

The heat conductivity properties of different crystals are clearly similar to their optical properties. The heat conductivity surface of optically uniaxial crystals has the form of an ellipsoid of rotation.

For optically biaxial crystals, i.e., crystals of the orthorhombic, monoclinic, and triclinic systems, the surface of heat conductivity has the form of an ellipsoid with three unequal axes. It has two cross-sections in which heat conductivity of some crystals may be 3 to 4 times higher in some directions than in others. It is usually higher than that of amorphous substances of the same chemical composition.

ELECTRICAL PROPERTIES OF CRYSTALS

The electrical conductivity of crystals, in contrast to that of amorphous bodies, varies with direction. There are two kinds of electrical conductivity -ion conductivity, which is inherent in solutions and electron conductivity (in metals).

Resistivity of quartz (a dielectric) in the direction of the principal axis is hundreds of times lower than in the directions perpendicular to it. Resistivity increases considerably with an increase in temperature. The resistivity of metals also varies with direction.

but the variations are negligible. The increase of temperature has less effect on metals than on non-conducting crystals.

Of great interest are the pyroelectric and piezoelectric properties of crystals. These properties have acquired a considerable industrial importance.

MAGNETIC PROPERTIES OF CRYSTALS

In order to determine whether a substance is paramagnetic or diamagnetic it is necessary to disturb the orientation of its particles. The substance is crushed into fine powder which is placed in a glass capillary suspended by a thread in a magnetic field.

Induced para-on diamagnetism is equally strong in all directions only in singly refracting crystals. A ball made from such a crystal will occupy no definite position in a magnetic field.

Anisotropy of Physical Properties of Single Crystals

The physical properties of single crystals in general depend on the direction along which they are measured relative to crystal axes. This phenomenon is called 'anisotrophy'. Some examples are the following crystals do not grow in spheres, but in polyhedra, certain types of atomic planes dissolve more readily than others, the co-efficient of thermal expansion of Zn is $6{\cdot}39\times10^{-5}$ along the hexagonal axis and $1{\cdot}41\times10^{-5}$ per °c perpendicular to it. In electrical properties, the specific resistivities of Zn parallel and perpendicular to the hexagonal axis are respectively $P_{11}=6{\cdot}06\times10^{-6}$ and $P_1=5{\cdot}83\times10^{-6}$ Ohm/Cm. Similar anisotropy also exists in magnetic properties, e.g., susceptibility. The reason for the anisotropy of physical properties of crystals must be sought in regular stacking of atoms. Thus as one passes through a crystalline arrangement of atoms or molecules along a given direction, one meets atoms or groups of atoms at different intervals and from different angles than one would along another direction. Single molecules are also anisotropic. However, in normal liquids and gases or in polycrystalline solids, the completely random distribution of atoms or molecules or grains makes it isotropic. If, however, the randomness can be destroyed in the grains by properly aligning them. the anisotropy will again be observed. This can be seen in the phenomenon of magnetisation of a piece of iron.

As an example of anisotropy in a single crystal, let us consider the electrical conductivity in which an electric field $\vec{E}$ gives rise to a current $\vec{I}$. In general, these two vectors will not have the same

direction. The same direction between $\vec{I}$ and $\vec{E}$ is obtained only when the applied field falls along any one of the three principal axes of the crystal. Also, in general, the electrical conductivities along the three principal axes have different magnitude.

In cubic crystals, these three quantities are equal and the specific resistivity does not vary with direction. In hexagonal, rhombohedral and tetragonal crystals, the resistivity depends only on the angle ϕ between the direction in which P is measured and the axis, since in these crystals two of the three quantities P_1, P_2, P_3 are equal.

$$P(\phi)=P_1 \sin^2\phi+P_{11} \cos^2\phi$$

Where 1 and 11 refer to directions perpendicular are parallel to the axis. In other crystals the expression is more complicated.

CHAPTER V

ATOMIC STRUCTURE OF CRYSTALS

Crystals are solids bounded by flat surfaces and are built up by the repetition of unit cells in a regular geometrical arrangement. The study of internal arrangement of atoms in a crystal, i.e., the atomic structure of a crystal has been made by the X-Ray Analysis method.

In late 1895, Rontgen in Germany discovered a very unusual type of radiation which he called X-rays. They caused many substances to florescence, affect a photographic plate, traversed opaque objects, were undeflected by electric or magnetic fields, travelled in straight lines and were produced when cathode rays struck any solid body. The first analysis of X-ray diffraction by crystals was made in 1912 by Laue on Crystals of Zinc Blende on Sodium Chloride, as X-rays were light waves of wave length of the order of 1°A and the crystal behaved as a three-dimensional diffraction grating. The diffracted rays fell on a photographic plate, and the photograph showed a series of spots which formed a more or less symmetrical pattern. From measurements made on the photograph, the arrangement of the atoms in the crystal can be deduced and their inter-distances calculated. The wave length of X-rays and the lattice-space in the crystal can be measured in angstroms ($1A^\circ = 10^{-8}$ cm).

Unit Cell : The fundamental element of structure in a crystal is known as *Unit Cell.* Each crystal consists of a regularly ordered arrangement of atoms in a three-dimensional pattern, repeated exactly in all directions and is symmetrical. The smallest unit of three-dimensional pattern is called unit cell. The array of points in space at which the pattern repeats itself is called the 'lattice'.

To some extent, the choice of a group of atoms of a cell is arbitrary, in that there are usually a number of different equivalent ways in which the choice can be made. It can be shown that, by following standard symmetry operations, 14 simple lattices can be constructed; these are called Bravais Lattices. As for example, in the case of NaCl-crystal, the Na-atoms and Cl-atoms are arranged at the corners of a series of cubes, as shown in Fig. 23. The unit cell of sodium chloride contains four atoms of Na and four atoms of Cl.

Atomic Bonds : There are four principal types of *atomic bonds*

which hold together the atoms in different crystal structures. They are

(i) Ionic or heteropolar,
(ii) Covalent or homopolar,
(iii) Metallic and
(iv) Residual.

(i) *Ionic Bond:* The electrically charged atoms, called ions, are held together by electrostatic attraction, forming what is called an *Ionic Bond.* Positive and negative ions are mutually attracted by each other and produce Ionic or heteropolar bond in a crystal. Example: $Na^+ + Cl = NaCl$. These crystals have low coefficients of expansions, high hardness and high melting points.

Co-valent Bond: The co-valent or homopolar bond is due to joint sharing of one or more electrons between two atoms. As for example, a hydrogen gas molecule share the two orbital electrons of two atoms and thus they form a molecule.

$$H^{\cdot} + {}^{\cdot}H \longrightarrow H:H$$

Similarly for oxygen, which has six outer electrons, two electrons from each of two atoms are shared in forming a molecule. Diamond, provides of the best examples of a homopolar structure. Made entirely of carbon, the basis of the diamond structure is tetrahedral, where each carbon atom is surrounded by four others arranged at the corners. Carbon has four outer electrons, thus requiring four others to form four homopolar bonds.

Metallic Bond: Metals contain free electrons. The easy heatting up of metals and high electrical conductivity is due to the freely moving electrons through the metals. Metallic bond is due to the mutual attraction between positively charged atomic nucleus and the aggregate cloud of electrons. Thus, valency electrons are common to all atoms. The metallic bond is thus the attraction between the +Ve ions and the "gas" of −Ve electrons; it differs from the ionic bond in that it is exerted on like metal ions, not between ions of different elements, such crystals are called metallic crystals. Metals (e.g., Copper, Nickel, Iron, etc.); other metallic elements (e.g., Allumimium, Lead, Zinc, etc.) possess the property in a smaller degree, since they have a more or less typical structure.

There are three typical ways in which the metallic ions are packed to form a crystal. They are known as

(i) Cubic close packing, e.g., Copper,
(ii) Body centred cubic packing, e.g., iron at ordinary temperature,
(iii) Hexagonal close packing, e.g., magnesium.

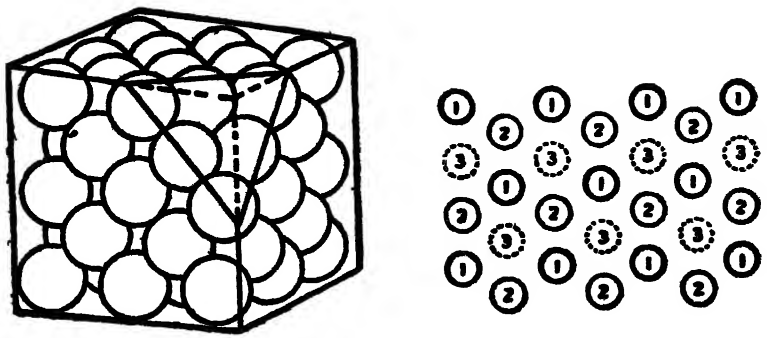


Fig. 23

(i) *Cubic close packing:* When the spheres, which represents the metallic ions, are all of equal size, the layer of ions which lie at right angles to a diagonal of cube, have the close-packing with the ions at the corners of equilateral triangles. As there are four diagonals, so there are four directions in which layers of this type occur. Examples: Copper, Gold, Silver, Platinum.

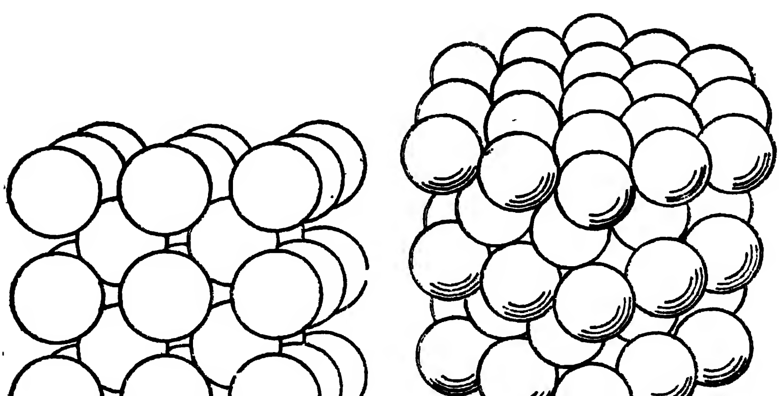


Fig. 24

(ii) *Body Centred Cubic Packing:* Here the ions, lie at the corners of a series of cubes and at the centres of the cubes. This structure is found in Iron. It makes iron malleable. Other examples are: tungsten, barium, vanadium and molybdenum.

(iii) ***Hexagonal close packing:*** Hexagonal close-packing shows a series of similarly stacked layers. In each layer the spheres are closely packed, with their centres lying at the corners of equilateral triangles. Adjacent layers are displaced relatively to one another. Magnesium, Titanium are typical examples.

Residual Bond: This bond differs from other types, in that it is not alone responsible for the coherence of any common substance Here the structural units are connected by the so called Van der Waals forces or residual forces, which are much weaker than the three other types.

Ionic Crystals: Crystals whose component atoms are held together as ions are called *ionic crystals*. They include most of the compounds of inorganic chemistry and the rock-forming minerals.

Ionic Radii: It is convenient to think the ions as spheres having a definite radius. When two ions are brought close together, a force of repulsion between them sets in when they are at a certain distance apart depending on the ions and increases rapidly for any closer approach. There is also the electrostatic attractive force existing between the ions. In equilibrium the separation is such that the two forces are equal in magnitude. The distance between their centres is then taken as the sum of the radii of the two ions. In this way the ions are treated as spheres in contact and by various methods, their radii can be measured.

Co-ordination: In ionic crystals each positive ion (cation) is surrounded by a number of negative ions, at a distance fixed by the sum of their radii. The number of negative ions around any one cation is called the *Co-ordination number*, and is determined by the ratio of the radii of the two kinds of ions. The metals aluminium, iron, magnesium and titanium, among others, are also found in 6-fold co-ordination.

Isomorphous Substitution: Isomorphous replacement of cations by others of similar size and equal charge is common in silicates. Thus Fe^{++} readily replaces Mg^{++}, the two ions having nearly the same size, and Fe^{3+} replaces Al^{3+}. Such replacement is random and results in the minerals concerned having variable compositions. The possibility of isomorphous substitution depends more upon ionic size than upon valency. This is well shown by the fact that Na^{+} is commonly replaced by Ca^{++} (as in the plagioclase felspars), but less readily by K^{+}, the explanation being that the Na and Ca ions have almost the same dimensions, whereas K-ion is considerably larger than Na-ion.

Silicate Structures: The fundamental unit in the building of silicate minerals is the SiO_4 – group, in which the silicon atom (or

more strictly, cation) is situated at the centre of a tetrahedron whose corners are occupied by four oxygen atoms. The distance between the centres of two adjacent oxygents is 2·7 A. U. i.e., almost exactly twice the radius of the oxygen. Classification of the silicates is based on the different ways in which the SiO_4 – tetrahedra occur, either separately or linked together. They are as follows:

(a) *Separate SiO_4 – groups (orthosilicates)*: The separate tetrahedra are stacked together in a regular manner throughout a crystal structure and are linked together only through the medium of other cations which lie between them. An example of a mineral built up in this way Olivine, Mg_2SiO_4. Considering the valencies of the elements composing the SiO_4 group, we see that silicon has four positive and each oxygen two negative valencies, i.e., there are eight negative valencies in all the group as a whole therefore has four negative valencies in excess.

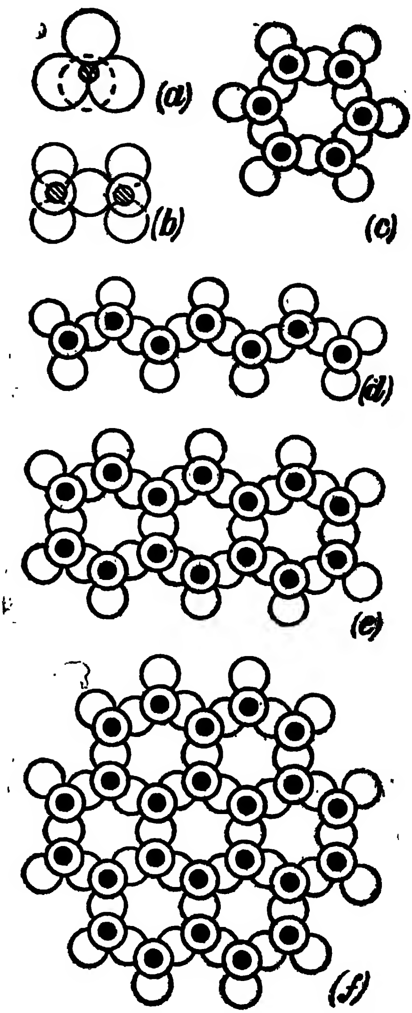


Fig. 25. Silicates structures : open circle represent oxygen atom ; silicate is shown by dots.

(b) *Structures with Si_2O_7 groups*: In some minerals the SiO_4–tetrahedra occur in pairs, in which one oxygen is shared between the two silicons and is inert. The composition of each pair of tetrahedra is then Si_2O_7 and these units are spaced throughout the crystal and bound together by other cations. The charge on any Si_2O_7 – group

is—6 $(=2\times4-7\times2)$, so that three divalent ions are needed to balance it. The mineral melilite, $Ca_2MgSi_2O_7$, common in slags, has a structure of this kind; another example is hemimorphite, $(OH)_2 Zn_4Si_2O_7 \cdot H_2O$, in which water of crystallisation is also present.

(c) *Ring Structures:* When each SiO_4 — tetrahedron shares two of its oxygens with neighbouring tetrahedra they may be linked into rings, a ring of three tetrahedra has the composition Si_3O_9 and one of six tetrahedra Si_6O_{18} (both formulae being multiples of SiO_3). An example of the former is the mineral benitoite, $BaTi(Si_3O_9)$; and of the latter, Beryl, $Be_3Al_2(Si_6O_{18})$.

(d) *Chain Structures, Si_2O_6:* A linkage of tetrahedra similar to that in the rings, but forming straight chains, is found in the important group of rock forming minerals known as the pyroxenes. The chains consist of a large number of linked SiO_4 groups, each sharing two oxygens and have the composition $n(Si_2O_6)$.

(e) *Double Chain Structures (Si_4O_{11}):* When two single chains are placed side by side, with the apexes of tetrahedra all pointing one way, and are linked by sharing oxygen atoms at regular intervals, a double chain results, whose composition is Si_4O_{11}. This type of structure is found in the amphiboles, a large group of rock forming minerals of which tremolite, $Ca_2Mg_5(Si_4O_{11})_2(OH)_2$, may be taken as an example. All the amphiboles contain hydroxyl, (OH), as an essential constituent, to the extent of about one (OH) radical to eleven oxygens. Some OH may be replaced by F. The (OH)—groups fit into the spaces in the structure, this content of hydroxyl was formerly spoken of as "Water of Crystallisation".

(f) *Sheet Structure, (Si_4O_{10}):* A sheet structure is formed when the SiO_4 — tetrahedra are linked by three of the corners, and extend indefinitely in a two-dimensional network or "sheet", which has a silicon : oxygen ratio of 4 : 10. This is found in the micas, chlorites and other flaky minerals. For example, the mineral pyrophyllite has the composition $Al_2Si_4O_{10}(OH)_2$.

(g) *Framework Structures, SiO_2:* A three-dimensional framework is formed when each tetrahedron is linked by all four corners, so that every oxygen ion is shared between two tetrahedra. This gives a silicon : oxygen ratio of 1 : 2 and the charges on such a framework are balanced. Minerals which have this structure include quartz (SiO_2) and other forms of silica, and also the important group of the feldspars, in which aluminium replaces some of the silicon. The Chief feldspars are: (i) Orthoclase, $KAlSi_3O_8$; here one-quarter of the silicon is substituted by aluminium, and for every Si-ion thus replaced one K-ion is introduced, and is accommodated in large interstices in the framework. By reckoning up the ionic charges, + and

—, we see that the constitution is neutral. (ii) Albite, $NaAlSi_3O_8$, with Na instead of K. (iii) Anorthite, $Ca(Al_2Si_2)O_8$; here half the silicon is replaced by aluminium, and a diavalent atom (Ca) is needed to restore electrical neutrality.

Classification of Crystals according to the Nature of Interatomic Forces

A qualitative discussion may be here about the forces acting between atoms or molecules in solids.

From the very existence of solids, we may draw two general conclusions :—

1. There must act attractive forces between the atoms or molecules of solid, which keep them together.
2. There must exist repulsive forces acting between the atoms or molecules, since large external pressure are required to compress a solid to any appreciable extent. The forces acting between the atoms in solids are electrostatic in nature i.e., they are determined by the way in which the outer electrons of the atoms are distributed in space, so it is possible on an empirical basis to divide solids into different groups corresponding to different types of electron distribution.

We may classify as,

(a) Ionic Crystals (NaCl, KF),
(b) Valence Crystals (diamond, SiC),
(c) Metals (Cu, Ag),
(d) Van der Waals Crystals (argon, many organic crystals).

CHAPTER VI

OPTICAL PROPERTIES OF MINERALS

Certain minerals are best studied in reflected light, using an "Petrological or Polarising Micoscope" and is an important part of mineralogy. The description of rock forming minerals for determinative purpose depends on certain optical properties.

Polarizing Microscope : A polarising microscope or a petrological microscope is one of the most important instruments used in the study of thin sections of minerals and rocks. The essential parts of the microscope are as follows shown in the Fig 26. Two nicol prisms are fitted in the microscope tube—one between the illuminating mirror *L* and the round rotating stage with a fixed scale *S* called the polariser *P* and another called analyser *A* inside a tube between objective and the eye piece. Polaroid (artificial products) or polarising light filters are often as polarising plates instead of the Nicol prisms. Between the lower nicol or the polariser and the stage there is pivoted a condensing lens or condenser *C*. Between the analyser and the eye piece there is another lens *B*, the Bertrand lens which can be inserted into the slot or removed from the optical system when necessary for studying mineral slides. At the lower part of the tube have a slot arranged at an angle of 45° to the symmetrical plane of the microscope, for introducing a quartz wedge, mica plate or a gypsum plate. The eye piece contains cross-wires at right angles. The objectives of high, moderate and low power are put to use for studying minerals and rocks and can be aligned with the axis of the microscope. An iris diaphragm with an aperture is usually fitted in the microscope in order

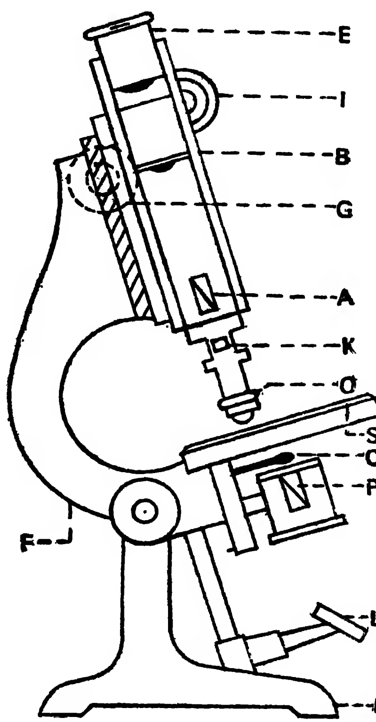


Fig. 26. Polarising Microscope.

to vary the amount taken in. The mirror *L* is used for illumination from ordinary day light or from artificial source. When the Becke test is to be performed for the determination of refractive index, moderate power objective is used and iris diaphragm is also used for the closer of aperture. The polariser and analyser are used for studying extinction angle, interference colour, twinning, etc. The Bertrand lens, high power objective and condenser are used for the study of interference figure.

The Nicol Prism : The Nicol prism or Nicol is an essential part of the polarising microscope. The nicol prisms are used for studying optical properties of minerals, such as extinction angle, interference colour, twinning, etc. The Nicol prism was invented by *J.* Nicol in 1828 and was named after him. The Nicol prism is made of perfectly

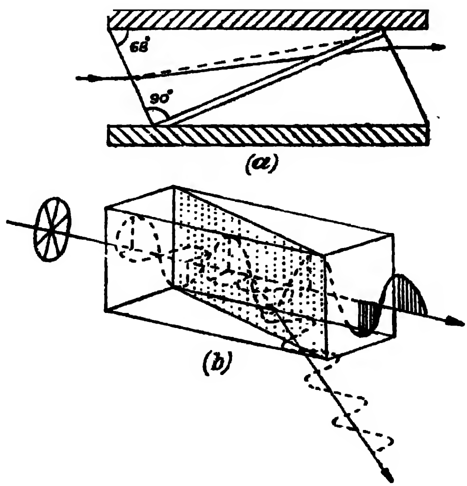


Fig. 27. Nicol Prism
(a) Showing Ordinary ray of light totally reflected by the layer of Canada Balsam while Extraordinary Ray of light is transmitted
(b) Showing ray path.

transparent, colourless, doubly refracting Calcite ($CaCO_3$), which is known as Iceland spar. It shows very strong birefringence and it has perfect cleavage parallel to three planes of a rhombohedron. The ends of the Calcite are ground to give a 68° angle to the long edge and the Calcite is cut into two pieces longitudinally by a plane from one corner to another which have three obtuse angles. Then the two pieces are recemented together with Canada balsam. On entering the prism a ray of light *OL* is doubly refracted into the ordinary ray *o* and an extraordinary ray *e*. The ordinary ray *o* reaches the Canada balsam at an angle greater than the critical angle, suffers total reflection

and is driven on to the black prism holder. The extraordinary ray *e* passes through the calcite rhomb, so that polarised extraordinary ray *e* emerges.

Nature of light :

Light is a form of energy which may be considered to consist of an undulatory motion. Light is regarded as a phenomenon caused by harmonic vibration of electromagnetic wave perpendicular to its direction of propagation. ***Light wave*** can be defined as a periodic disturbance in a medium or in space, which may involve the elastic displacement of material particles or a periodic change in some physical quantity such as temperature, pressure, electric potential, electromagnetic field strength, etc. ***Wave motion*** is the propagation of a periodic disturbance carrying energy. At any point along the path of a wave motion, a periodic displacement or vibration about a mean position takes place. The *Wave length* of a wave is the distance between successive points of equal phase of a wave. The *phase* of a particle at a given instant is its position in the variation and the direction in which it is moving. The *wave form* is the shape of a wave, illustrated graphically by plotting the values of the periodic quantity against time. The time required for the disturbances to travel one wave length is called the *period.* The *wave form* is the shape of a wave, illustrated graphically by plotting the values of the periodic quantity against time. In the wave form, the particles L_1 and L_3 are in the same phase, and L_1 and L_2 differ in phase by half a wave-length. The *wave length* is equal to the velocity of the wave motion divided by its frequency. For electromagnetic radiation $\lambda = \frac{C}{\upsilon}$, where C is the velocity of light and υ is the frequency. The colour depends upon the wave length of the light causing it. The wave-length of light is commonly given in millimicrons, i.e. millionths of a millimeter, the symbol being mμ For red light 707 mμ, for green 505 mμ for violet light 424 mμ etc. Monochromatic light is light of one wave-length only. *The wave front* is the locus of adjacent points in the path of wave motion which possesses the same phase.

Polarised Light : Ordinary light consists of electric and magnetic vibrations taking place in all possible planes containing the ray, the vibration the associated vibration takes place in a plane at right angles to the direction of the light path. i e. light is a transverse wave motion. Light is said to be *plane polarised* or *polarised,* if the light in which the waves vibrate in only one plane, as distinct from ordinary light in which the vibrations take place in all directions perpendicular to the direction of propagation of the ray. For use in a petrological microscope, light is commonly polarised by passing it through *Polaroid* or a *Nicol Prism* (Polariser).

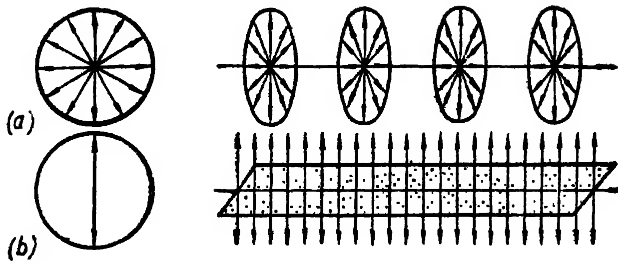


Fig. 28 (a) & (b) Showing Polarisation of light.

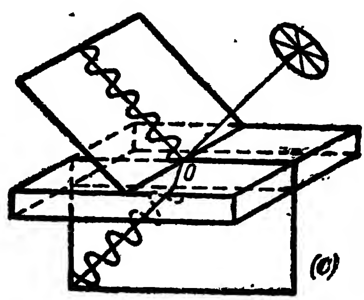


Fig. 28 (c) Showing Polarisation by reflection and refraction.

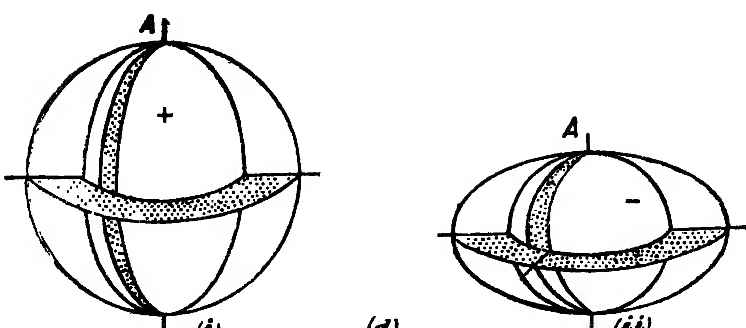


Fig. 28 (d)
(i) Wave fronts in a positive Uniaxial Crystal.
(ii) Wave fronts in a negative Uniaxial Crystal.

In *plane polarised light* only the polariser of the microscope is used. When a thin section of a mineral (of ·035 mm thickness) is studied in polarised light *between crossed nicols* both polariser and analyser of the microscope with their polarisation lying at right angles are used. Identification of minerals in thin sections under the petrological microscope is an important part of mineralogy. The description of minerals for determinative purpose depends on certain optical properties, chief among which are the following:

I. In Plane polarised light
   (*a*) Colour
   (*b*) Pleochroism
   (*c*) Refractive index
   (*d*) Cleavage
   (*e*) Shape and Habit
   (*f*) Alteration
   (*g*) Inclusion

II. *Between Crossed nicols*
   (*a*) Optic Characters
   (*b*) Interference Colours
   (*c*) Birefringence
   (*d*) Extinction
   (*e*) Twinning
   (*f*) Sign of elongation
   (*g*) Optic angle, 2v

Colour: In thin section, the colour of a mineral can be observed under the petrological microscope and it is made visible due to transmission of light through the same. Minerals may be colourless or coloured in different tints. The colour depends on the kind of light reflected or transmitted, as determined by the selective absorption. In an isotropic mineral light rays vibrating within the mineral in all directions will have the same velocity and the colour of the mineral will be the same in all directions. Uniaxial and biaxial minerals have respectively two (ω, ϵ) and three (X, Y, Z) vibration directions of light rays and the selective absorption, to which the colour of a mineral is due, often varies with the crystallographic direction in which light vibrates inside the mineral. Thus anisotropic minerals may have different colours corresponding to different vibration directions, i.e. they may show pleochroism.

Pleochroism: The pleochroism of a mineral, in thin section, can be observed under the microscope. The slide containing a thin section mineral is placed upon the stage of the microscope and the stage is rotated gradually to note the change of colours, if any. If the colour of the mineral remains unchanged in different positions of

rotations of the microscope stage, the mineral is said to be *non-pleochroic*. If the colour of the mineral is found to change gradually from one colour to another when the stage of the microscope is rotated. Some of the minerals like quartz, Feldspar, etc. are non-pleochroic and hornblende, biotite, etc. shows very characteristic pleochroism in them, are said to be *pleochroic*. The *pleochroic haloes* are characteristics of certain minerals and are readily visible under the microscope. Minute inclusions are found in some minerals under the microscope, which are more strongly visible than the main part of the mineral. These pleochroic inclusions are called pleochroic haloes, which are due to the products of disintegration of radioactive substances within the main mineral.

A uniaxial mineral has two vibration directions (1) ordinary ray (ϵ) (2) extraordinary ray (ω) ; they being mutually perpendicular. A biaxial mineral has three vibration directions X, Y, Z at right angles to one another. Certain minerals (both uniaxial or biaxial) show different colours, corresponding to different vibration directions. This property of differential absorption is known as pleochroism. (a) *Determination of pleochroic scheme of an uniaxial mineral :* Pleochroic scheme of a mineral consists of (1) pleochroic colours, (2) pleochroic or absorption formula. Prismatic sections parallel to '*c*' crystallographic axis contain both ω and ϵ vibration directions. The direction parallel to c-axis is ϵ vibration direction, perpendicular to it is ω_0 vibration direction. Thus a prismatic section of the mineral concerned (such as tourmaline) is to be taken to find out its scheme of pleochroism.

The mineral section is put on the microscopic stage. The nicols are crossed. The section of the mineral shows interference colour. The microscope stage is rotated until the mineral is extinguished. At this position, the two vibration directions are parallel to analyser and polariser. The analyser is removed. Then the colour corresponding to the one vibration directions which is parallel to the polariser, is noted. The microscope stage is rotated through 90° and the colour corresponding to the other ray is noted. Now knowing the slow and fast nature of light rays vibrating in the two directions by quartz wedge, sensitive tint, etc., the scheme of pleochroism can be fully known. In the case of tourmaline :

Absorption	ϵ = Slight yellow-brown
Colours	ω = Dark-brown
Pleochroic formula	$\omega > \epsilon$

ω denotes the refractive index of the ordinary ray

ϵ denotes the refractive index of the extraordinary ray

(b) *Scheme of pleochroism of biaxial minerals.* Biaxial minerals have

three vibration directions X, the fastest; Z, the slowest and Y some where between X and Z. Now to know the pleochroic nature of a biaxial mineral two sections containing ZX, YZ or XY are to be studied. In Hornblende, the section showing maximum extinction angle is the optic axial plane i.e. ZX plane. Sections showing two sets of cleavages at 124° contain X and Y vibrations. The complete scheme of pleochroism is derived by bringing each of the two vibration directions of the section concerned successively parallel with the vibration of the polarizer and noting down the colours and for the absorption formula, the relative strengths of colours. In the case of hornblende :

Absorption	$X =$ pale green
Colours	$Y =$ deep green
	$Z =$ deep bluish green

Pleochroic formula $Z > Y > X$. Pleochroism is best observed under the microscope by rotaing the polariser.

Refractive Index : The angle of incidence is i and the angle of refraction is r, it is for the same medium $\frac{Sin\ i}{Sin\ r}$ is a constant. The constant is called the *Refractive Index*. The velocity of light changes while passing from one medium to the other and this causes a change in the direction of light ray at the surface of separation between the two media. The degree of refraction is the ratio between the two velocities i.e. the refractive index. Light travelling through isotropic minerals in all directions have the same velocity and hence the same refractive index. Uniaxial minerals have two refractive indices corresponding to fast and slow axes in the mineral. Biaxial minerals have three vibration directions at right angles to one another X, the fastest; Z, the slowest, and Y, somewhere between the two, corresponding to which are the refractive indices. Uniaxial minerals have two refractive indices corresponding to fast and slow rays in the mineral. Biaxial minerals have three vibration directions at right angles to one another X, the fastest; Z, the slowest, and Y. somewhere between the two, corresponding to which are the refractive indices α, γ and β

Refractive indices are determined by the immersion method with the help of Becke Test. According to the test, when the microscope tube is raised the Becke line will move towards the material of higher refractive index and when the tube is lowered this line will move towards the material of lower index. By knowing the refractive indices of the comparing immersion liquids, the refractive indices of the mineral can be accurately determined to an accuracy of ± ·001.

To determine the refractive index of an isotropic mineral, the polariser should not be used, as the refractive index is the same for all directions of light vibrations. To determine the refractive indices

ϵ and ω of a uniaxial mineral, a prismatic section (parallel to C-axis) where both ϵ and ω are found, is selected. The direction corresponding to ϵ and ω are made parallel with the polariser and compared with the immersion liquids. To determine α, β, γ of a biaxial mineral. two sections must be selected. In an assemblage of biaxial mineral grains the section that gives the maximum interference colour between crossed nicols has the maximum probability of containing γ and α. The sections which remain dark between crossed nicols in all rotations of the microscope stage and give optic axis figure under convergent polarised light, would give β. Knowing the directions and comparing them with the immersion liquids by Becke Test, the refractive indices α, β and γ can be determined.

Cleavage : Cleavage is defined as the tendency of a crystalline mineral to break in smooth surfaces parallel to certain crystallographic directions. Cleavage planes are those planes of atomic structure in which the atoms are most closely packed together, while the distance between successive planes is relatively large. Cleavage, in one, two or three directions, is more frequent. Flourite has four sets of cleavage parallel to octahedral faces. Sphalerite has six sets of cleavage parallel to faces of a rhombic dodecahedron.

Shape and Habit : These refer to the geometric development of the mineral grain, i.e. the degree to which it is bounded by crystal faces, and to the overall shape as 'habit' of the crystal. According to development of faces, grains are described as euhedral, subhedral and anhedral. The habit is described as equant, tabular, lathshaped, prismatic, fibrous, acicular, etc.

Alteration : Alteration is the term applied to all changes in minerals subsequent to their formation. Alteration begins on the outer surfaces of minerals or along cleavage and fractures, etc. and penetrates them gradually through the cracks or cleavages. For example : olivine may be altered to serpentine along cracks.

Inclusion : A particle of mineral or glass or other matter when completely enclosed by a larger mineral grain, is known as an inclusion. Microscopic examination of mineral grains frequently show the presence of impurities in individual grains. For example, Leucite contains volcanic glass as inclusion, staurolite contains quartz grains as inclusions and quartz often contains bubble, like fluid inclusions.

Optic Character—Isotropic and Anisotropic : Minerals are either isotropic or anisotropic. *Isotropic minerals* in which light is transmitted with the uniform velocity throughout in all directions. Minerals crystallising in the Isometric System are isotropic. *Anisotropic minerals* possess different physical properties in different directions and in anisotropic minerals light is transmitted with different velocities in different directions. Anisotropic minerals are subdivided into

uniaxial and biaxial. *Uniaxial minerals* are tetragonal and hexagonal minerals and have one optic axis. *Biaxial minerals* comprise the rest of the anisotropic classes and have two optic axis. Uniaxial minerals are said to be *positive* when the ordinary ray has greater velocity than that of extraordinary ray. When the ordinary ray has less velocity than that of extraordinary ray, the uniaxial mineral are said to be *negative*. Minerals which crystallise in orthorhombic, monoclinic and triclinic systems, are said to be biaxial minerals. In biaxial minerals there are three optic directions X, Y and Z of which X is the fastest and Z is the slowest optic directions. The acute angle between the two optic axis of all biaxial minerals is known as $2V$ or *optic axial angle* and the line which bisects the acute angle, either the X and Z directions, is said to be *acute bisectrix*. A biaxial mineral is said to be *positive*, when the slow (Z) direction of vibration forms the acute bisectrix and a biaxial mineral is said to be *negative* as the fast (X) direction forms the acute bisectrix.

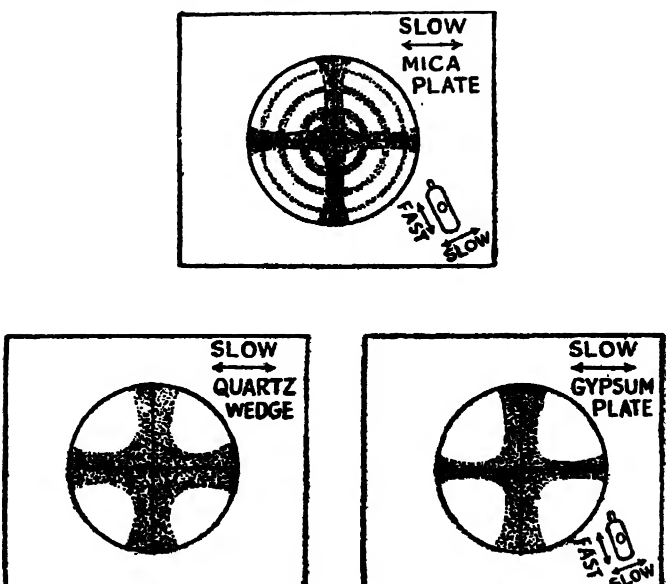
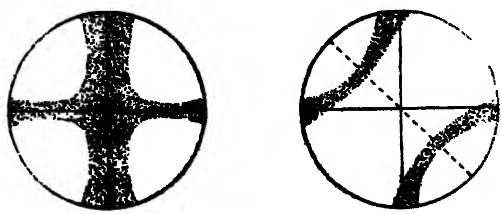


Fig. 29. Determination of Optical Sign of Uniaxial Mineral.

To determine uniaxial or biaxial character, commonly a grain with interference colour is selected for 'conoscopic' observation. The substage condenser lens of the microscope is inserted, a high power objective is used, and a Bertrand lens is inserted in the tube (or the eye piece is removed). An interference

figure will be seen. Its characters give the optical character of the mineral. A uniaxial figure is a straight cross with its arms parallel to the analyser and polariser (vibration direction) with circular colour rings, not always visible. If the cross is centred, the optic axis is truely vertical and there is no change on rotation of the stage otherwise the cross is off-centre or only one arm is visible at a time which moves parallel to itself and leaves the field, being replaced by another at right angles. The behaviour is understood if it is assumed to be due to rotation of a cross having its centre outside the field.



A B

Fig. 50. Acute bisectrix figure of Biaxial Mineral

A biaxial figure in its centred position is a cross with one arm thicker than the other and coloured bands in the form of lemniscates which are rarely seen. The cross breaks up on rotation into hyperbolas. This is a figure obtained from a section normal to the bisectrix of the acute angle between the optic axes (Bxa). However, by selecting a grain with very low interference colour, one is liable to get an optic axis figure.

This will be with a single bar, straight when parallel to the vibration directions of the nicols, curving in other positions (unless the $2V$ is 90° or nearly so). If the optic axis is vertical the bar will rotate about the centre, and with increasing deviation from the vertical the centre of the bar moves in a circle while the bar rotates.

Thus uniaxial and biaxial are easily recognised. To determine the optic sign from the figure requires the use of an accessory compensator plate e.g. the sensitive tint gypsum (if no colour rings are visible) or a $\frac{1}{4}$ λ mica plate.

Uniaxial minerals are said to be positive when $n_e > n_0$ and negative when the reverse. Under the microscope, for our purpose, if the ray with n_0 has greater velocity the mineral is positive. To do this a figure with the centre within the field of view is preferable. The accessory plate is inserted through a slot at 45° to the principal directions. The effect of its interference, are additive in alternate quadrants. If the 'length' of the plate is 'fast' then sign is determined

as follows. In alternate quadrant this length lies radially or tangentially to the figure i.e. parallel to o ray and e ray vibrations respectively, whichever ray is faster will give a rise in colour in its quadrant and there will be fall with very low colours, the sensitive tint plate (ordinarily red) gives blue and yellow in sections, which are easy to distinguish. Now if o is faster, the mineral is positive ; if e is slow the mineral is negative.

Biaxial minerals are determined in the 45° position, i.e. rotated 45° from position where bars are straight. Unless $2\,v=90°$; a curved bar is found. The tangent to the convex side gives the trace of the optic normal Y, the radial direction on the convex side gives the trace of the optic normal Y, the radial direction on the concave side gives the character of Bx_0 (bisectrix of the obtuse angle between the axes). By comparison the character of Bxa (acute bisectrix) is deduced. By definition, if Bxa is Z, the mineral is positive and X negative.

The accessory plate (say length 'fast') is inserted then either radially or tangentially occurs in the two sections on the concave and convex sides of the bar (if both bars are present the reaction is symmetrical across Y). If the length coincides with Y and a rise is found in that sector, then Y is faster than Bx_0 i.e. $Bx_0=Z$ i.e. $Bxa=X$ and the mineral is negative. The other cases are similarly deduced.

Isotropic and Anisotropic Minerals Between Crossed Nicols :

(a) Isotropic minerals give blackiness between crossed nicols at all positions of the microscopic stage. Anisotropic minerals give interference colours between crossed nicols.

(b) Anisotropic minerals are doubly refracting.

(c) Anisotropic minerals are divided into Uniaxial and biaxial. Uniaxial minerals have one optic axis and biaxial minerals have two optic axis.

(d) When the vertical crystallographic axis is fast, the Uniaxial mineral is optically negative and when the vertical crystallographic axis is slow, uniaxial mineral is optically positive. A biaxial mineral is said to be positive, when the slow (Z) direction of vibration forms the acute bisectrix and a biaxial mineral is said to be negative as the fast (X) direction forms the acute bisectrix.

(e) Anisotropic minerals show darkness or extinguish between crossed nicols four times during a complete revolution of the microscope stage.

(f) Isotropic minerals cannot exhibit birefringence and cannot have any twinning and extinction angle.

Isotropic and Anisotropic Minerals in Plane Polarised Light :

1. Isotropic minerals show the same colour and non-pleochroic. The absorption in isotropic minerals must be same in all directions.
2. Anisotropic minerals are both pleochroic and non-pleochroic. An anisotropic minerals is said to be pleochroic when it shows change in colour by rotating the polariser of the microscope.

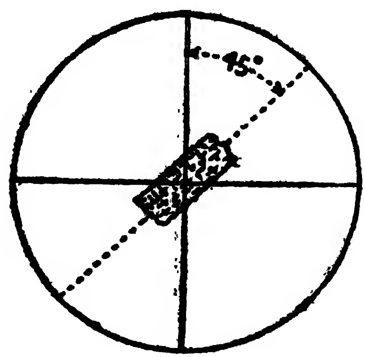


Fig. 31. Extinction angle of Augite, 45°.

Extinction : The anisotropic minerals extinguish or exhibit darkness between crossed nicols four times during a complete revolution of the microscope stage. The *extinction* takes place when the vibration planes of the mineral are parallel to the nicol planes.

There are various positions of extinction. In *parallel* or *straight extinction,* extinction occurs when crystallographic direction, cleavage, crystal axis. fractures, etc. are parallel with the cross wires of the Eye piece. *Oblique or inclined extinction* takes place when the crystallographic direction, cleavage, etc. are not parallel with the cross-wires and makes an angle with the cross-wires in the position of extinction of the mineral. The cross-wires in the position of extinction bisect the angle between the two cleavage directions is said to have *symmetrical extinction.*

The *extinction angle* of a mineral is defined as the acute angle between one of the vibration directions and axes of the crystallographic directions e.g. cleavages, crystal axes, fractures, etc. Extinction angle is usually measured with the cleavage traces. For example, in common hornblende, prismatic sections show cleavage traces of (110). The cleavage traces are parallel to the '*c*' crystallographic axis. Now in hornblende, the vibration directions are not parallel to the crystal axes. To measure the extinction angle, the thin section containing prisms of hornblende is seen in plain polarised light and

the cleavage traces are made parallel to the *NS* cross-wire. The microscope is then crossed. The mineral will show interference colour. The reading on the microscope stage is extinguished i.e. showing no interference colour. The reading is again taken, say 26°. The mineral shows extinction of colour because the vibrations are now parallel to the cross-wires. The angle (26°−5°) or 21° gives the angle between gives the angle between the cleavage traces (II to *C* axis) and one of the vibration direction. The character of the vibration direction is tested with a quartz or mica-plate and say *Z X*°. So the extinction angle of hornblende is $Z \wedge C = 21°$.

Twinning: Twinning can be best seen between crossed nicols. The two halves of the twin or the two sets of twin lamella, between crossed nicols, exhibit different polarisation colours or interference colours and extinguish at different angles.

Twinning in anisotropic mineral grains is discernible by petrographic methods. The units or individuals differ in orientation and thus in optical character in the same section and therefore, between crossed nicols a twin crystal appears to be composed of parts having different interference colours and having different extinction positions. Both *simple* (e.g. staurolite, orthoclase, sanidine) and *polysynthetic* (plagioclase microcline) are distinguishable, and polysynthetic twin characters form diagnostic criterion for the recognition of minerals. Plagioclase feldspar shows *lameller twinning* between crossed-nicols, exhibits two sets of twin lamellae, each set extinguishing in a different position from that of the other.

Sign of Elongation: Crystallised minerals (prismatic or platy) may be elongated along one of the crystallographic directions. The sign of elongation is determined with a quartz wedge mica plate or gypsum plate by knowing whether the light wave vibrating nearly parallel to the long direction of the crystal section is slow or fast with respect to the wave vibrating nearly at right angles to the length of the crystal section. If *Z* (the slowest) coincides with the axis of elongation, the sign of elongation is positive or the mineral is length-slow. If *X* (the fastest) occupies the position, the sign of elongation is negative or the mineral is length-fast.

Optic axial angle (2v) : A biaxial mineral has two optic axes; light travelling along them suffers no double refraction. The acute angle between the two optic axes is known as optic axis figure. 2v can be determined by the following methods of which, the method of determination with the universal stage is most accurate.

1. Estimation of 2v from acute bisectrix figure.
2. Estimation of 2v from optic axis figure.

3. Calculation of $2v$ from the refractive indices α, β, γ from the relation.

$$\tan^2 V = \frac{\dfrac{1}{\alpha^2} - \dfrac{1}{\beta^2}}{\dfrac{1}{\beta^2} - \dfrac{1}{\gamma^2}}$$

4. By actual measuring the angle between the optic axes with the universal stage.

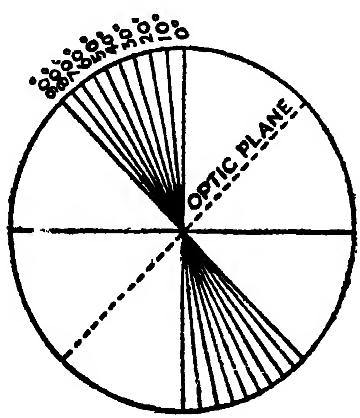


Fig. 31. Isogyres in optic axis figures of various values of 2v.

CHAPTER VII

OPTICAL PROPERTIES OF ORE MINERALS

Opaque minerals are best studied in reflected light, using an ore microscope. Ore microscopic study has two principal aspects, (i) identification of minerals and (ii) study of textural and paragenetic relations between the minerals. Identification under the ore microscope is an important part of mineralogy. The description of opaque minerals for determinative purpose depends on certain optical and physical properties, chief among which are the following :

1. Colour and pleochroism
2. Reflectivity
3. Crystal form and habit
4. Cleavage and parting
5. Hardness
6. Optic character (Isotropism/Anisotropism)
7. Twinning, zoning
8. Internal reflections.

Sometimes micro-chemical tests are also used, but only when a mineral cannot be identified by its physical characters. Any one or more of the physical characters may be specifically diagnostic. but a complete study of all properties should be made for conclusive determination. The various properties and their significances are discussed at length below.

Colour and Pleochroism : The colour (or colours) of a mineral in polished section in reflected plane polarised light is a valuable clue to its identity. Colours are best studied using a blue filter to correct the colour of light. Most ore minerals are coloured in shades of grey. Other common colours are white, yellow, pink, cream, blue, etc. The colour of a mineral often changes according to the character of neighbouring minerals, e.g. pyrite bordering galena is yellow, while pyrite against chalcopyrite looks almost white. The description of colour is largely subjective, and some colours, such as that pyrrhotite, may be said to be almost beyond description. However, experience will help in recognising colours and some peculiar colours will give positive identification by themselves alone. Some pleochroic changes e.g. that of covellite are also very helpful. Isotropic (isometric) minerals are obviously non-pleochroic, but all anisotropic minerals are not pleochroic, and even those that are, possess the property in varying degrees.

Some of the most common colours and minerals are given below :

1. White :	Galena Haematite (bluish) Pyrolusite (yellowish)
2. Grey :	Sphalerite (brownish) Magnetite Psilomelane
3. Yellow :	Chalcopyrite Pyrite Arsenopyrite (almost white)
4. Pink and brown	Pyrrhotite (creamy pink, or an undefinable colour known as pyrrhotite colour) Bornite Ilmenite
5. Blue :	Covellite Chalcocite

Reflectivity : This refers to the reflecting power of a mineral, and is expressed as the percentage of incident light reflected. Anisotropic minerals have reflectivity varying with orientation. Minerals may be classified on the basis of reflectivity as below :

1. Very high :	Arsenopyrite, Galena
2. High :	Pyrite, Pyrolusite, Chalcopyrite
3. Moderality high :	Haematite, Chalcocite, Bornite, Covellite
4. Moderately low :	Magnetite, Ilmenite
5. Low :	Sphalerite

Crystal form and habit : In general, the harder minerals, e.g. magnetite, pyrite, etc., tend to develop crystal boundaries in preference to softer minerals. When found, crystal shapes are often valuable clues to the identity of the mineral, and are always important in paragenetic study. For instance magnetite octahedra, arsenopyrite prisms, pyrite cubes, etc. are very common.

Cleavage and parting : Cleavages show up in polished sections as sets of parallel cracks, forming pits where they intersect. In most cases the cleavage cracks are faintly visible, but in minerals with many cleavages, e.g. galena, the triangular pits formed by intersection are arranged in rows along the cleavage traces.

Hardness: The hardness of minerals is tested under the microscope by using a sharp steel needle with a weighted handle. The point is brought into the field of view of the microscope, held at an angle to the vertical, and dragged over the polished surface. Minerals scratched under the weight of the handle alone are said to be soft, those requiring moderate pressure intermediate, and those which can be scratched with difficulty or not at all, hard.

Optic Character (Isotropism/Anisotropism): Isometric crystals between crossed nicols in reflected light will remain dark or show only two positions of extinction, 180° apart, on rotation of the stage. Some minerals, such as covellite, show four positions of extinction and this character is of diagnostic value. The colours seen between crossed nicols are known as anisotropic colours and are most commonly various shades of brown and green, but red, blue, etc. are also seen. Anisotropism is best studied without any filter on the light and, in case of most minerals, with the nicols slightly off true crossed position (analyser rotated about 5°).

Strongly anisotropic :	Covellite, Pyrrhotite Ilmenite, Arsenopyrite Pyrolusite Psilomelane etc.
Weakly anisotropic :	Chalcocite, Chalcopyrite, Haematite, etc.

Twinning and Zoning: Twinning is often detectable in plane polarised light by crystallographic characters, such as cleavage; or rarely by different pleochroism of halves. This is also the only way to detect twinning in isotropic minerals. Twinning in anisotropic minerals is best seen between crossed nicols.

Zoning is usually visible between crossed nicols, due to the difference in anisotropism with varying composition.

Internal Reflections: Some minerals such as sphalerite are not completely opaque, but allows some light to penetrate. This light is reflected from cleavage planes or grain boundaries, and has a characteristic colour which helps in identification.

Etch-Tests: If a chemically active solution is placed on a polished surface, a reaction takes place which affects different minerals to a different degree. This brings out the texture of the minerals and sometimes causes a characteristic tarnish. Some common etching reagents are given below :

HNO_3 (1 : 1), HCL (1 : 1), KCN (20% by weight solution), FCl_3 (20% solution), KOH (40%), $Hg\ Cl_2$ (5%). H_2O_2, Aqua regia, etc.

CHAPTER VIII

ORIGIN, OCCURRENCE AND ASSOCIATION OF MINERAL

A *mineral* is a homogenous substance, having a definite chemical composition and a definite atomic structure and produced by the process of inorganic nature. Diamond, Chalcopyrite, Hematite, Quartz, Calcite are examples of minerals. Ice, water and mercury are also regarded as mineral. Mineral, occurs naturally in the earth's crust which consist chiefly of organic hydrocarbons, which is used for producing heat energy, either by means of the release of its chemical energy by combustion or its nuclear energy by nuclear fission, which are called *Mineral fuel*, such as coal, petroleum, atomic or radio active minerals.

Rocks are aggregates of minerals and forms the part of the earth's crust. Rocks can be broadly divided into three main classes (i) Igneous, (ii) Sedimentary, (iii) Metamorphic.

There are two classes of minerals found in the earth's crust. Most abundance in the earth's crust are the *rock-forming minerals*, such as quartz, feldspars, etc. There are another class of minerals which though less in relative abundance in the earth's crust, is important from the economic point of view, which are known as *ore-forming minerals*.

Mineral Origin : During solidification of magmas, the constituent minerals solidify in descending order of their melting points. The most refractory mineral crystallizes earliest while those, with lower melting points, follow in succession.

From Fusion : The major part of the minerals that form the earth's crust have been formed by the consolidification from magma (fused rock material).

From Solution : Some minerals have been formed by crystallisation from solutions in descending order of their melting points. Minerals, also formed from the solutions in the cracks, joints and fissures of the rocks are called *vein* minerals. Minerals have also been formed by the evaporation of saline water and by precipitation from ground waters, such as borax, halite, etc.

From Vapour : Some minerals that form the earth's crust have been formed by the crystallization from a gas. Minerals which formed from vapours are confined to such volcanic regions where mineral gases are discharged from fumeroles. Minerals deposited in this process include minerals of sulphur, arsenic, chlorides, tellurium, boric

acid, etc. All minerals, whether metallic or non-metallic, are primarily derived from a liquid or gaseous state. Their formation, therefore, is largely influenced by pressure and temperature. Generally, decrease in temperature and pressure decreases the solubility of materials in solution and promote their precipitation.

The other major factors that control the processes of mineralisation are :

(a) Solubility of the mineral matters
(b) Nature of solvent
(c) Concentration of mineral matter
(d) Nature of country rocks

Under favourable circumstances. the formation of economic minerals may take place in the following major ways :

Concentration from magmas : During the cooling and consolidation of magmas. various minerals of economic importance may form by direct crystallisation from the magmas at various stages of their cooling history. These include the heavy minerals like Magnetite, Chromite, Ilmenite, Apatite, etc. which settle in the lower part of the magma mass and salic extracts of Tin. Tungsten. Beryllium, rare earths, Uranium, etc. which move towards the upper part of the magma.

Reaction of Magmatic fluids : Gaseous emanations released during igneous activities may enter into reactions among themselves or with other gases. liquids or solids with which they may come in contact and thus gives rise to economic minerals. Thus native sulphur may form due to the reaction of H_2S gas with SO_2 gas ; Copper Sulphide may be precipitated from Cupric Sulphate solutions by H_2S and contact-metasomatic minerals like Copper Sulphide, Galena, Cassiterite, Graphite, etc. may originate from the reaction of gaseous emanations with invaded solid rocks.

Similarly, magmatic solutions may react among themselves and other liquids or solids and produce a number of important minerals. The most important among them are those produced by metasomatic replacement of solid rocks. e.g. Cassiterite, Wolframite. Graphite, Sphalerite, etc. and those by oxidation and reduction of solution. e.g. Copper sulphide. They may also be direct deposition from the magmatic solutions in open spaces, e.g. Gold tellurides. phosphatic compounds, nickel compounds, etc.

Precipitation by Bacteria : Bacteria often cause precipitation of important minerals from their solutions in nature. A striking example is the precipitation of Iron by bacteria. Anaerobic bacteria are powerful agents to precipitate Sulphides and Sulphur.

Colloidal Deposition : In some colloidal solutions electrically charged fine particles remain in suspension in a liquid medium. These

are called suspensoids. Addition of some electrolyte in suspensoids neutralizes the charge of the particles which are then quickly flocculated. Minerals showing colloform banding e.g. Psilomelane are thought to have been produced in this way.

Evaporation of solutions: Minerals like Gypsum and certain Copper and Iron Ores are supposed to have precipitated from solutions due to evaporation of the solvents causing supersaturation.

Distillation: Petroleum is widely believed to be the result of distillation of organic materials caught up in the submarine sediments.

Metamorphism: During the metamorphism of rocks, whether thermal or regional, various minerals of economic importance are formed at the expense of pre-existing minerals. Common examples are Garnet, Sillimanite, Kyanite, Graphite, etc.

Weathering and Sedimentation: Rocks and mineral deposits when subjected to weathering may give rise to some new minerals of economic value. For example, feldspathic rocks are converted into kaolin masses by weathering. The newly formed minerals may exist in situ or may be carried away by ground waters and deposited in other places.

OCCURRENCE OF MINERALS

Minerals are found to occur in nature as rock constituents in the form or disseminations, fissure veins lodes, and in beds. They are formed in three major environments: Igneous Environment, Sedimentary Environment and Metamorphic Environment. The *Rock forming minerals* may be divided into Silicate Minerals and Non-silicate minerals.

The *Silicate Minerals* are Quartz group, Feldspar group, Feldspathoid group, Olivine group, Pyroxene group, Amphibole group, Mica group, Garnet group and clay minerals. The *Non-silicate minerals* are Carbonates, Halides, Sulphates, Oxides and Sulphides minerals Among the rock forming minerals, some of them occur as essential or major minerals, which occur in large numbers and some minerals occur small and scattered crystals in the rock, there are known as accessory minerals. Some of the major rock forming mineral, are as follows:

Quartz:	Uusually occurs in igneous and other types of rocks, gem varieties found in pegmatite viens.
Feldspars (Orthoclase, Plagioclase Microcline etc):	Found in basic igneous rocks.
Muscovite and Biotite:	Found to occur in many igneous and metamorphic rocks.

Amphibole (Hornblende etc.) : Found to occur in basic igneous rocks.

Pyroxence (Augite, etc.) : Found to occur in basic igneous rocks.

The most common accessory rocks forming minerals are epidote, kyanite, sillimanite, zircon, staurolite, garnet, apatite, etc. The rare accessory rock forming minerals are magnetite, rutite, hematite, ilmenite, pyrite, andalusite, etc.

ASSOCIATION OF MINERALS

The association of minerals or their *paragenesis* is of great importance and significance in their study. The rock forming minerals and the economic minerals are found to occur within three types of igneous, sedimentary and metamorphic rocks. It is found that the different kinds of rocks are characterised by their own typical mineral assemblages.

Association in Igneous rocks: In igneous rocks the common mineral associations are quartz, orthoclase, plagioclase, muscovite, and biotite. Olivine, pyroxenes and amphibole minerals are found to be associated with the basic and ultrabasic igneous rocks. The copper ores and some other metallic ores are associated with the acid igneous rocks. The chromite and few other metallic minerals occur in association with basic and ultrabasic rocks.

Association in Sedimentary rocks: Sedimentary rocks are secondary in their origin, the minerals which are found in these types of rocks are products of weathering of the pre-existing rocks, i.e. igneous and metamorphic rocks. In sedimentary rocks, the common mineral associations are quartz, feldspar, mica, pyroxene, amphibole, mica, calcite, garnet, chlorite, etc.

Association in Metamorphic Rocks: Metamorphic rocks are rocks which have undergone some physical and chemical change subsequent to their pre-existing formation i.e. igneous and sedimentary rocks. These types of rocks produced from the pre-existing rocks, i.e. igneous and sedimentary rocks by the action of high temperatures and pressures upon them. Typical metamorphic minerals are kyanite, sillimanite, staurolite, andalusite, chlorite, garnet, epidote, talc and cordierite. The mineral assemblage produced under metamorphic conditions depends upon the composition of the original rock and the conditions of its metamorphism.

The Chief Rock-forming Silicate Minerals of Igneous and Metamorphic Rocks are Orthoclase, Microcline, Plagioclase, Pyroxene (augite), Amphibole (hornblende), Muscovite (Mica), Biotite (Black

Mica), Olivine, Leucite, Chlorite, Serpentine, Beryl, Topaz. Tourmaline and Zircon, etc.

The Silicate Minerals characteristics of Metamorphic Rocks are Andalusite, Asbestos, Cordierite, Epidote, Garnet, Idocrase, Kyanite, Sillimanite. Staurolite, Talc, etc.

The mineral associations, characteristics of different rocks and economic mineral deposits are as follows (Agol and Gurevich).

Minerals of endogenous formations:

1. Minerals of plutonic igneous rocks of diverse composition and of magmatic ore deposits.
2. Principal mineral associations in pegmatites.
3. Mineral associations in contact-metasomatic formations.
4. Minerals of hydrothermal deposits of Economic minerals.
5. Minerals of effusive rocks and products of fumarole activity.

Minerals of exogenous formations :

1. Minerals of the crust of weathering.
2 Minerals of sedimentary rocks and of economic deposits.

Minerals resulting from regional metamorphism :

1. Minerals of metamorphosed rocks and ore deposits.

CHAPTER IX

MINERAL ECONOMICS

Mineral Economics is a vital aspect of present day economy. A country's economy is essentially linked up with her national mineral policy.

For a balanced development and management of a country's mineral resources, a synthesis of the related theories and practices of Geological Science, Economics and Political Science is absolutely necessary. This synthesis may be defined as *Mineral Economics*.

Concept : The very concept of Mineral Economics emerges from the standpoint of mineral localisation of their exhaustibity. The need for increasing mineral production and to maintain future supplies, it is necessary to develop a separate branch of Geological Science which require a specialised study of mineral reserve, excavation, research, planning and development of allied industries and all other related problems.

Scope of Study : This specialised study is all the more important for providing the proper background to personnel in mineral administration in Government or Private Industry. The study provides a thorough and intrinsic knowledge of the mineral wealth of a country and their profitable harnessing from the standpoint of economics. The site selection of the mining industry is a difficult job requiring great scrutiny. Not only the proximity of the deposits but also the cheap availability of power or fuel for industries are also to be looked into.

National Mineral Policy : National mineral policy takes into account a wide range of considerations. First of all, it deals with geopolitics. Global distribution of different minerals in different geological horizons, has made a certain country rich in one or several minerals in one hand and on the other hand, there could be dearth of certain other minerals. Accordingly a nation builds up a mineral policy of her own. It focusses on certain minerals, which are grouped as strategic minerals, such as Radioactive elements, base metals, etc. Strategic mineral may be defined as the minerals in which a country has more or less negligible resource available and depends upon import of minerals from other countries.

Secondly, mineral economics ties up these processes together. These are exploration of minerals, exploitation of minerals, haulage, consumption and marketing of minerals. Specially, in India, this has led to the concept of formation of mineral economy, which is the summation of public and private sector enterprises. Here, also, a certain factor plays its role. In Indian context, Coal, Iron, Copper, Lead, Zinc, Aluminium industries cannot go into the hands of private sector. Accordingly, these have been nationalised.

A third factor, is also there. That is the problem of monopoly. It is as such a cocktail problem. O.P.E.C. (Organisation of Petroleum Exporting Countries) in many cases threatens the rest of the world by stopping their export. To face the problem, different countries are changing their policies—in cases it is less consumption and in others, the thing is to get the thing at the expense of other mineral. This creates unstability in country's economy.

The Governmental attitude towards the development of its mineral resources is depicted in the National Mineral Policy. The approach can be from two view points, namely the domestic and foreign investments. Every country having different mineral resources searches for new minerals and their profitable harnessing with indigenous know-how, the primary aim being the attainment of self-sufficiency.

Thus the policy, on the whole, should be based on a realistic knowledge of the country's potential and its richness in mineral resources. There should be adequate scope for reorienting the whole policy upon new discoveries of mineral reserves. The formulation of the mineral policy is universally recognised to be guided by four axioms.

(i) No nation has the domestic resources for catering to its total need.
(ii) The minerals are a depleting assets.
(iii) Modern industrial economics are based on minerals and mineral fuels.
(iv) Boundaries of countries bear little or no relation to mineral Geography.

Thus the frame-work of the mineral policy is based on (i) appraisal of mineral wealth, (ii) Mining rights, (iii) Mine safety, (iv) Mineral taxation policy, (v) Imposing of protective tariff and quota system, (vi) Conservation and substitution, (vii) New metallurgical methods and (viii) Mineral storage programme.

Domestic Mineral Policy : * The first Mineral Policy formulation was made in the Industrial Policy Resolution of 6th April, 1948, which included some large investment mineral industry requiring a high degree of technical skill and kept under the purview of Central regulation and control. This was superseded by the Industrial Policy Resolution of 30th April, 1956. Under this the mineral have been put in three categories. The first category includes mining and processing of coal and lignite, mineral oil and gas, gypsum, sulphur, gold, diamond, copper, lead, zinc, tin, molybdenum and tungsten ores, and minerals specified in the Atomic Energy (control of production and use) Order

* Shina, R. K. and Sharma, N. L. : Mineral Economics, Oxford & IBH Publishing Co.

1953. The Second category contains all other minerals, excluding minor minerals. The third category consists of minor minerals. To implement the policy underlined the above Resolution, suitable provisions have been made under the Mines and Minerals (Regulations and Development) Act, 1957 and Coal bearing Areas (Aquisition and Development) Act, 1957.

ECONOMIC IMPORTANCE OF MINERALS

Minerals and Rocks are indispensable to human life. They are the basic resources essential to the rapid development and successful execution of industrial projects. From the earliest times down to the present, the ascent of man, his growing culture and civilization, his advancement—the story of man's progress has been closely linked with materials and mineral substances. Minerals and Rocks of economic value have a variety of use.

We know that the tremendous role played in human life by iron extracted from iron-rich ores by smelting the iron ores into various grades of iron and steels. Iron and steel play the vital role in various industrial prospects, ship building, railway transport, bridges, metallurgy, manufacture of mining machinery and the production of various consumer goods. Coal, Petroleum and Natural gas play an important economic role.

The non-ferrous metal like copper, zinc, lead, aluminium, nickel, cobalt, molybdenum, tungsten, titanium, vanadium, etc. are greatly used in the aircraft industry, electrical engineering, ship building, etc. In order to enhance the fertility of the soil and thereby to maintain good productivity, it is essential to use fertiliser in the agricultural soil. The chief mineral fertilisers are minerals containing potassium (potassium salts), nitrogen (nitre), phosphorus (apatites, phosphorites), etc. The minerals are used in the chemical industries are pyrite, native sulphur, fluorspar, minerals of potassium, sodium, magnesium, boron, nitre and mercury. The minerals like Barite, late and sulphur are used in the rubber iidustry. Talc. Kaolin, Sulphur, alum, magnesite etc. are used in paint industry. Asbestos, quartz, graphite, etc. are used in heat and acid resistance. Kaolin, dolomite, magnesite, graphite, quartz are used as refractory substances.

Minerals and their salts are also used for human diet, for the manufacture of medicine. Gemstones and coloured stones are used as ornaments and jewellery. Iceland spar (calcite), quartz, muscovite, fluorite and tourmaline are used in optical instruments. Diamond (carbonadum), corundum, quartz, agate, zircon and other hard minerals make good bearings for watches and precision instruments.

Radioactive minerals are important for the power generation and industry.

CHAPTER X

DESCRIPTIVE MINERALOGY

This part of Mineralogy includes the classification of minerals, chemical, physical, optical properties of minerals, crystalline form and mode of mineral occurrence.

Classification of Minerals

The classification of minerals should be crystallochemical and based on the knowledge of the interrelationship of all properties of natural chemical compounds and their chemical composition and crystal structure (V. Agol and A. Gurevich).

All natural formations comprising the subject of mineralogy, as well as artificial substances in chemistry, are divided into two big independent groups (according to Agol and Gurevich).

(i) Inorganic minerals which, apart from rarely occurring native elements, include natural compounds (except organic compounds) of all the chemical elements ;

(ii) Organic minerals comprising diverse compounds of carbon (except carbonates and carbides which are closed with the inorganic compounds).

The scheme of classification adopted by Dana is as follows :

I. Native Elements.

II. Sulphides, Selenides, Tellurides, Arsenides, Antimonides.

III. Sulfo-salts—Sulpharsenites, Sulphantimonites, Sulphobismuthites.

IV. Halides—Chlorides, Bromides, Iodides, Fluorides.

V. Oxides.

VI. Oxygen salts—Carbonates, Silicates, Titanates, Niobates, Tantalates, Phosphates, Arsenates. Vanadates, Antimonates, Nitrates, Borates, Uranates, Sulphates, Chromates, Tellurates, Tungstates, Molybdates.

VII. Salts of Organic Acids,—Oxalates, Mellates, etc.

VIII. Hydrocarbon Compounds.

The second scheme of classification adopted by H. H. Read based

on Periodic classification of the elements is as follows :

Group I.	(a) Lithium, Sodium, Potassium. (b) Copper, Silver, Gold.
Group II.	(a) Calcium, Strontium, Barium (Radium). (b) Beryllium, Magnesium, Zinc, Cadmium, Mercury.
Group III.	(a) Boron, Aluminium.
Group IV.	(a) Titanium, Zirconium, Cerium, Thorium. (b) Carbon, Silicon, Tin, Lead.
Group V.	(a) Vanadium, Tantalum. (b) Nitrogen, Phosphorus, Arsenic, Antimony, Bismuth.
Group VI.	(a) Chromium, Molybdenum, Tungsten, Uranium. (b) Sulphur, Selenium, Tellurium.
Group VII.	(a) Manganese. (b) Fluorine, Chlorine, Bromine, Iodine.
Group VIII.	(a) Iron, Cobalt, Nickel. (b) Ruthenium, Rhodium, Palladium, Osmium, Iridium, Platinum.

Abbreviations Used

Chemical Composition	COMP.
Crystal System	CRYST SYST.
Common Form & Structure	COM. FORM.
Cleavage	CLEAV.
Fracture	FRACT.
Hardness	H.
Specific Gravity	SP. GR.
Special Properties	SPEC. PROPS.
Optical Properties	OPT. PROPS.

LITHIUM MINERALS

Lithium minerals (Li) does not occur in a free state in nature and few occur as compounds. They occur in altered granites and in pegmatites, sometimes in hydrothermal veins and are associated commonly with quartz, muscovite, feldspars, spodumen, topaz, fluorite, tourmaline, cassiterite, etc. Lithium salts are used in alkali storage batteries, optical glass, in fire works, photography, medicine, for making hydrogen bomb, in high energy fuels for rockets and guided missiles. The principal Lithium minerals are :

Lpidolite or Lithia-mica	..	$KLiFe. Al (Si_3 AlO_{10}) (F, OH)_2$
Zinnwaldite or Lithia-iron mica	..	$KLiFe. Al(Si_3 AO_{10}) (F, OH)_2$
Petalite	..	$Li (Al Si_4) O_{10}$
Spodumene	..	$Li Al Si_2 O_6$
Amblygonite	..	$Li (F, OH) Al PO_4$

LEPIDOLITE

COMP. Lithium aluminium silicate, $KLi Al_2 Si_3 O_{10} (F, OH)_2$ CRYST. SYST. Monoclinic. COM FORM. Tabular, pseudohexagonal prism, pinacoid and prism, CLEAV. Basal, imperfect COLOUR. Pink, pale violet, rose red. LUSTRE. Pearly and vitreous, silvery or cleavage surface H. 2-3. SP, GR. 2·8-3. OCCURRESCE. Occurs in pegmatite associated with topaz, tourmaline, etc. OCCURRENCE. In India occurs in Monghyr, Hazaribagh of Bihar; Bastar district in Madhya Pradesh.

ZINNWALDITE

COMP. Lithia-iron mica, KLi Fe. AL $(Si_3 AlO_{10}) (F, OH)_2$. CRYST. SYST. Monoclinic. COM. FORM. tabular ; CLEAV. Perfect, one set basal. COLOUR. Pale violet, yellow, brown and sometimes grey. LUSTRE. Vitreous, pearly on cleavage surface. H. 2–3. SP. GR. 2·9–3·2.

SPODUMENE

COMP. Lithium aluminium silicate, $Li Al Si_2O_6$ CRYST. SYST. Monoclinic COM. FORM. Crystals made up of prism, pinacoids and domes. CLEAV. Perfect, parallel to the prism, parting on (100). COLOUR. Greyish white or yellowish green. Gem varieties are *Hiddenite*, the emerald-green and *Kunzite*, lilac, transparent. LUSTRE. Vitreous, pearly on cleavage surfaces. H. 6·5–7. SP. GR. 3·13-3·20. OCCURRENCE. In India, in mining area of Kashmir and Mysore found in pegmatites.

SODIUM MINERALS

Sodium (Na) minerals does not occur in a free state in nature. Silicate sodium minerals occur as rock forming silicates in pegmatites, granites and in other igneous, sedimentary and metamorphic rocks. The non-silicate sodium minerals occur as saline residue deposited by the evaporation of salt water. Metallic sodium may be produced by the reduction of sodium hydroxide NaOH. by carbon or by decomposition of a melt of the hydroxide by an electric current. Sodium is a soft slivery white metal, easily tarnishing in the air, it decomposes water, forming hydrogen and hydroxide. The principal sodium minerals :

Chloride	Rock salt, Halite,	$NaCl$
Nitrate	Soda-nitre,	$Na\,NO_3$
Sulphates	Thenardite,	Na_2SO_4
	Mirabilite,	$Na_2SO_4 \cdot 10H_2O$
	Glauberite,	$Na_2SO_4 \cdot CaSO_4$
	Thermonatrite,	$Na_2CO_3 \cdot H_2O$
	Natron,	$Na_2CO_3 \cdot 10H_2O$
	Trona,	$Na_2CO_3 \quad NaHCO_3 \quad 2H_2O$
	Gaylussite,	$Na_2CO_3 \cdot CaCO_3\, 5H_2O$
Borates	Borax,	$Na_2B_4O_7 \cdot 10H_2O$
	Ulexite,	$Na\,CaB_5O_9 \cdot 8H_2O$
Fluoride	Cryolite,	Na_3AlF_6

HALITE, ROCK-SALT, COMMON SALT

COMP. Sodium Chloride, NaCl. CRYST. SYST. Isometric, (Cubic), Galena type, Crystalline often massive. CLEAV. Perfect, 3 sets, cubic. COLOUR. Colourless or white, often yellowish or reddish. STREAK. white LUSTRE. Vitreous ; transparent to transulent, FRACT. Uneven, brittle, conchoidal. H. 2-2·5. SP. GR. light, 2·2. SP. PROP. Soluble in water, saline to taste. OCCURRENCE. Halite occur as sedimentary bedded deposits, these are the result of the evaporation of enclosed or partly enclosed bodies of sea-water. In India, Rock salt are found in association with bedded sedimentary rocks in Mandi in Himachal Pradesh. Major source of common salt based on sea water are in West Bengal, Orissa, Gujarat, Tamil Nadu, Andhra Pradesh & Maharastra. USES : Used for preserving purposes manufacture of sodium carbonate, etc.

BORAX

COMP. Na_2O, $2B_2O_3$, $10H_2O$. Hydrated Sodium borate CRYST. SYST. Monoclinic. COM. FORM. Prismatic crystals, massive. CLEAV. Perfect, parallel. COLOUR. White STREAK. White. LUSTRE. Vitreous, sometimes earthy. FRACT. Conchoidal, brittle. H. 2—2·5 SP. GR. Very light 1·7 SP. PROP. Sweetish alkaline. OCCURRENCE. occur in saline lakes and dried beds between Ladakh region (Puga) in Kashmir and Tibet, in and in Gujarat, in Rajasthan in India. USES. used for the manufacture of sodium carbonate for making glass, soap; etc.

CRYOLITE

COMP. Fluoride of aluminium and sodium, $Na_3 AiF_6$. CRYST. SYST. Monoclinic. COM. FORM. massive, cleavable with a lameller structure. CLEAV. Perfect, parallel. COLOUR. Colourless or snow-white. STREAK. Uncoloured. LUSTRE. Vitreous. FRACT. Uneven, brittle. H. 2·5. SP. GR. 2·97 OCCURRENCE : Occurs in pegmatite vein in granite, associated with fluorite, zinc blende, galena, siderite, etc. and occurs in Gujarat, Madhya Pradesh and Rajasthan. USES : used in the manufacture of white porcelain ware and aluminium and for making sodium and aluminium salts SODA-NITRE. Nitratine, Nitrate of Soda, Chile Saltpetro.

POTASSIUM MINERALS

Potassium (K) minerals does not occur in a free state in nature. Silicate potassium minerals occur as rocks forming silicates in pegmatites, granites and in other igneous rocks. The non-silicate potassium minerals occur as saline residue deposited by the evaporation of salt water. Metallic Potassium may be produced by the reduction of potassium hydroxide by carbon or by decomposition of a melt of the hydroxide by an electric current. Potassium is a soft silvery white metal, easily tarnishing in the air it decomposes water, forming hydrogen and hydroxide. Potassium minerals are used as fertilisers, in the manufacture of explosives, in chemical and metallurgical purposes.

The principal potassium minerals are :

Silicates	Orthoclase	$KAlSi_3O_8$
	Leucite	$KAlSi_2O_6$
	Muscovite	$KAl_2(AlSi_3)O_{10}(OH)_2$
Chloride	Sylvine	KCl
	Cornallite	$KCl \cdot MgCl_2 \cdot 6H_2O$
	Kainite	$KCl \cdot MgSO_4 \cdot 3H_2O$

Sulphates	Polyhalite	$K_2SO_4 . MgSO_4 . 2CaSO_4 . 2H_2O$
	Alunite	$KAl_3 (SO_4)_2(OH)_6$
Nitrate	Nitre	KNO_3

SYLVINE, Sylvite

COMP. Potassium Chloride, KCL. CRYST. SYST. Isometric COM. FORM. Cube, octahedron, massive and granular. COLOUR. White or colourless. STREAK. white CLEAV. perfect, cubic. LUSTRE. Vitreous. H. 2. SP. GR. 2. SP. PROP. Soluble in water, saline to taste. OCCURRENCE. Occurs as a saline residue and as deposits, associated with rock salts and other potassium minerals.

CARNALLITE

COMP. KCL. Mg Cl_2 $6H_2O$, Hydrated chloride of potassium and magnesium. CRYST. SYST. Orthorhombic. COM. FORM, massive and granular COLOUR. white, pink, reddish. STREAK. White. CLEAV. absent. FRACT. Conchoidal. H. 3. SP. GR. 1·6. SP. PROP. Soluble in water, bitter to taste. OCCURRENCE. Occurs as saline residue. USES. used as fertilizer and a source of potassium salts.

ALUNITE, Alumstone

COMP. KAl_3 $(SO_4)_2$ $(OH)_2$, hydrated sulphate of potassium and aluminium. CRYST. SYST. Hexagonal COM. FORM. massive, granular. earthy, crystals rare, rhombohedral. COLOUR. white, reddish or greenish. STREAK. white. CLEAV. parallel to basal plane. LUSTRE. Vitreous. FRACT. Conchoidal, Uneven. H. 3·5-4. SP. GR. 2·6. OCCURRENCE. occurs as an alteration or replacement of rhyolites and trachytes. USES. Used as a source of potassium and aluminium salts.

NITRE, Saltpetre

COMP. KNO_3, postassium nitrate. CRYST. SYST. Orthorhombic COM. FORM. Acicular crystals. COLOUR White. STREAK. White. LUSTRE. Vitreous. H. 2, SP. GR. 2·1, SP, PROP, Saline and Cooling, OCCURRENCE. Occurs in the loose earth forming the floors of natural caves. USES. used as a fertiliser, in the manufacture of explosives and in the chemical and metallurgical purposes.

GLAUCONITE

COMP. K_2 $(Mg, Fe)_2$ Al_6 $(Si_4 O_{10})_3$ $(OH)_{12}$. Hydrous silicate of iron and potassium with aluminium, magnesium and calcium. CRYST. SYST. None, Amorphous. COM. FORM. in colloidal and

crystalline forms. COLOUR. Dull green. STREAK. Greenish. CLEAV. Imperfect. LUSTRE. Dull or glistening. FRACT. Uneven. H. 2. SP. GR. 2·2-2·4. OCCURRENCE. Occurs in Chalk marl, Chloritic marl, Sandstone.

COPPER MINERALS

Next to iron, Copper (Cu) is by far the most important metal essential to modern civilization. Even in by-gone days, Copper was mined and smelted in considerable quantities, all over the world. As regards India, remains of old excavations, mounds of copper slag and articles made of copper or its alloys testify that in the past copper mining was in vouge in this country as well.

In nature Copper occurs in principal forms, viz. Oxides, Sulphides, Sulphate, Carbonates, Silicates, Chloride and as Native Copper. Of these the bulk of Copper is obtained from the sulphides ores. Impurities, such as lead, zinc gold and silver minerals are not uncommon in Copper ores.

The Chief Copper minerals are as follows:

Element	Native Copper, Cu
Oxides	Cuprite, Cu_2O
	Tenorite, CuO
Sulphides ..	Chalcopyrite, $CuFeS_2$
	Chalcocite, Cu_2S
	Covellite, CuS
	Bornite, Cu_5FeS_4
Gray Copper ore	Tetrahedrite, $(CuFe)_{12}Sb_4S_{13}$
	Energite, $Cu_3 AS S_4$
	Tennantite, $(CuFe)_{12}AS_4S_{13}$
	Bournonite, $Cu Pb Sb S_3$
	Famatinite, $Cu_3 Sb S_4$
Sulphate ..	Chalcanthite, $CuSO_4 . 5H_2O$
Carbonates ..	Malachite, $CuCO_3 . Cu(OH)_2$
	Azurite, $2 CuCO_3Cu(OH)_2$
Silicates ..	Chrysocolla, $CuSiO_3 . 2H_2O$
	Dioptase, H_2CuSiO_4
Chloride ..	Atacamite, $CuCl_2 . 3Cu(OH)_2$

NATIVE COPPER

COMP. Cu., Pure Copper. CRYST. SYST. Isometric, COM, FORM. Massive, irregular and lenticular bodies, fissure veins, as twinned crystals. COLOUR. Copper red. STREAK. shinning and metallic. CLEAV. Absent. LUSTRE. Metallic. FRACT, Hackly malleable, ductite. H. 2·5–3 SP. GR. 8·80. OCCURRENCE, Occurs as hydro thermal and metasomatic deposit filling cracks. amygdales. USES. As an ore of Copper.

CUPRITE

COMP. Cu_2O, Copper Oxide. CRYST. SYST. Isometric. COM. FORM. Crystalline, octahedron and rhombdodecahedron. COLOUR. Cochineal red. STREAK. Brownish red. CLEAV. Absent or not perfect. LUSTRE. Adamantine, submetallic or earthy. FRACT. Conchoidal, uneven or brittle. H. 3·5-4 SP. GR. 5·8-6·1. OCCURRENCE. Occurs in the zone of weathering of Copper lodes. USE. Used as an ore of Copper. Other varieties of cuprite are *Ruby Copper*, crystalline cuprite, *Chalcotrichite*, fibrous crystals of a beautiful cochineal-red-colour.

CHALCOPYRITE

COMP. Cu Fe S_2, sulphide of Copper and iron. CRYST. SYST. Tetragonal. COM. FORM. Massive or crystalline, twinned crystals. COLOUR. Golden yellow. STREAK. Greenish black. LUSTRE. Metallic. CLEAV. Imperfect. FRACT. Conchoidal, Uneven. H. 3·5-4 SP. GR. 4·1-4·3. OCCURRENCE. Occurs as hydrothermal or metasomatic veins, as Magmatic seggregations. In India Copper occurs in Singhbhum district of Bihar and in the Khetri Copper Belt in Rajasthan. USE. As an Copper ore, used for coinage. ammunition, copper plating, in battery.

CHALCOCITE

COMP. Cu_2S, Copper sulphide. CRYST. SYST. Orthorhombic. COM. FORM. Usually massive or granular, twinned crystals frequently, combinations of pinacoids and prisms. COLOUR. Blackish lead grey. STREAK. Blackish lead grey, sometimes shining. CLEAV. Imperfect. LUSTRE. Metallic. FRACT. Conchoidal H. 2·5-3. SP. GR. 5·5-5·8. OCCURRENCE. Occurs in beds or veins associated with other copper minerals. USE. An important ore of copper.

COVELLITE

COMP. CuS. Copper sulphide. CRYST. SYST. Hexagonal. COM. FORM. Usually massive, crystalline. COLOUR. Indigo blue.

STREAK. Lead grey to black. CLEAV. Perfect, basal. LUSTRE. Sub-metallic to resinous. H. 1·5-2. SP. GR. 4·6. OCCURRENCE. Occurs in the secondary enrichment of Copper lodes, etc.

BORNITE

COMP. Cu_5FeS_4, Sulphide of Copper and iron. CRYST. SYST. Isometric. COM. FORM. Usually massive; in crystals, cube, octahedron. COLOUR. Pinchbeck brown or Coppery red. STREAK. Pale greyish-black. CLEAV. Perfect in crystals and absent in massive form. LUSTRE. Metallic. FRACT. Conchoidal uneven, brittle. H. 3. SP. GR. 4·9-5·4. OCCURRENCE. Occurs as a primary deposit in many Copper lodes. It forms veins with quartz, or with quartz and chalcopyrite. USE. Used as a valuable ore of Copper.

TETRAHEDRITE

COMP. $(Cu\,Fe)_{12}\,Sb_4\,S_{13}$. Sulphide of Copper and antimony. CRYST. SYST. Isometric, Tetrahedrite type. COM. FORM. Tetrahedral crystals, also cryptocrystalline structure, massive with compact or granular. COLOUR. Steel grey to iron black. STREAK. Iron black. CLEAV. Perfect in crystals LUSTRE. Metallic. FRACT. Conchoidal or uneven, sometimes brittle. H. 3-4·5. SP. GR. 4·5-5·1. OCCURRENCE. Occurs associated with other ores of Copper, and also with Zinc-blende, Siderite and Galena.

ENARGITE

COMP. $Cu_3\,As\,S_4$, Sulphide of Copper and arsenic. CRYST. SYST. Orthorhombic. COM. FORM. Massive and granular; twinned crystals. COLOUR. Greyish black to iron-black. STREAK. Greyish black. LUSTRE. Metallic. FRACT. Uneven, brittle H. 3, SP, GR, 4·4. OCCURRENCE. Occurs with other ores of Copper in veins. USE. Used as an ore of Copper and arsenic.

MALACHITE

COMP. $CuCO_3$. Hydrated basic carbonate of Copper. CRYST. SYST. Monocllinic. COM. FORM. Massive, granular, earthy, botryoidal mammillated, Stalactilic. COLOUR. Bright green. STREAK. Green. CLEAV. Perfect. LUSTRE. Silky or earthy. FRACT. Uneven. H. 3-5°4. SP. GR. 3·9-4. OCCURRENCE. Occurs in the Zone of oxidation or weathering of Copper deposits, lodes or other types. USE. As an ore of Copper.

AZURITE

COMP. $2Cu\,CO_3$. $Cu\,(OH)_2$. Hydrated basic carbonate of Copper. CRYST. SYST. Monocinic. COM. FORM. Usually massive or earthy. COLOUR. Deep azure blue. STREAK. Blue. LUSTRE.

Vitreous to earthy. FRACT. Conchoidal. H. 3·5-4, SP. GR. 3·7-3·9, OCCURRENCE. Occurs in association with other oxidised Copper minerals in the zone of weathering of copper lodes and deposits. USE. As an ore of copper.

SILVER MINERALS

Silver (Ag) occurs in native state but it also occurs in combination with other elements as compounds. It is usually associated with other metals such as gold, copper, mercury, platinum and bismuth, etc.

Silver is used for monetary purposes, ornaments silverware, in photographic industry. as chemicals, for soldering and in electric industry.

Silver ores occur as replacement deposits, contact metamorphic deposits, veins and as alluvials. Most silver deposits have been formed as replacements or as cavity fillings by hydrothermal solutions.

In India silver occurs in Zawar and Mewar in Rajasthan, Kolar in Karnataka, Hazaribagh, and Manbhum districts in Bihar and in some districts of Madhya Pradesh. Silver is obtained as by product during smelting of galena (PbS) found at Zawar in Udaipur districts of Rajasthan. Silver is also found in combination with gold in the Kolar gold field in Karnataka and in Andhra Pradesh.

The principal silver minerals are:

Element	..	..	Native Silver, Ag.
Sulphide	..	..	Argentite. Ag_2S Stephanite, Ag_5SbS_4 Pyrargyrite, Ag_3SbS_3 Prousitite, Ag_3AsS_3 Polybasite, $(Ag, Cu)_{16}(Sb, As)_2S_{11}$
Telluride	..	..	Hessite, Ag_2Te
Chloride	..	..	Cerargyrite, AgCl

NATIVE SILVER

COMP. Ag, silver. CRYST. SYST. Isometric. COM. FORM. Massive, and distorted crystals. COLOUR. Silver white. STREAK. Silver white. CLEAV. Imperfect. LUSTRE. Metallic. FRACT. Maleable, hackly and ductile. H. 2·5-3. SP. GR. 10·1-11·1. OCCURRENCE. Occurs in the upper parts of Silver sulphide lodes.

ARGENTITE

COMP. Ag_2S. Silver sulphide. CRYT. SYST. Isometric. COM. FORM. Massive. crystal show octahedron, cube and distorted. COLOUR. Blackish lead grey. STREAK. Lead grey. shinning.

CLEAV. Perfect in crystals and absent in massive form. LUSTRE. Metallic. FRACT. Conchoidal or uneven. H. 2—2·5 SP. GR. 7·19-7·36. OCCURRENCE. Occurs in various types of viens USE. An ore of copper.

PYRARGYRITE

COMP. Ag_3SbS_3. Sulphide of silver and antimony, CRYST. SYST. Hexagonal. COM. FORM. Massive, and crystals. COLOUR. Black or Cochineal-red. STREAK. Conchineal-red. LUSTRE. Matellic, adamantine. FRACT. Conchoidal. H. 2·3. SP. GR. 5·7-5·9. OCCURRENCE. Occurs in veins and replacement-veins of various types.

HESSITE

COMP. Ag_2Te. Silver telluride. CRYST. SYST. Isometric. COM. FORM. Massive. COLOUR. Lead-grey. STREAK. Lead-grey. LUSTRE. Metallic. FRACT. Conchoidal. H. 2·5. SP. GR, 8·4. OCCURRENCE. Occurs with tellurides in veins.

CERARGYRITE, HORN SILVER.

COMP. Silver Chloride, AgCl. CRYST. SYST. Isometric. COM, FORM. Massive or crystal, cube. COLOUR. Palegrey sometimes green on bluish STREAK. Shining. LUSTRE. Resinous. FRACT. Conchoidal. H. 2·3. SP. GR. 5·8. OCCURRENCE. Occurs in the Upper parts of the veins associated with other silver minerals.

GOLD MINERALS

Gold (Au) occurs free in nature. the metal also occurs in association with silver, Copper, bismuth, mercury, and other metals. The Gold ore minerals are associated with pyrite, pyrrhotite are arsenopyrite. The common gangue minerals of gold are quartz, carbonates, tourmaline, fluorspar and few other non-metals.

The economic gold minerals are native gold and minor amounts of gold amalgam, tellurides and electrum.

The chief gold minerals are :

Element	..	..	Native Gold, Au.
Amalgam	..	..	Gold Amalgam, Au with Hg, Ag.
			Calaverite (Au, Ag) Te_2
			Sylvanite (Au, Ag) Te_2
Tellurides	..	..	Petzite $(Ag, Au)_2 Te$
			Nagyagite, (Au, Pb) Te, S.

NATIVE GOLD

COMP. Au. Pure gold. CRYST. SYST. Isometric. COM. FORM. Usually found in grains and scales, rarely in crystals,

octahedron, rhombdodecahedron, cube. COLOUR. Yellow. STREAK. Yellow. CLEAV. Perfect in crystals. LUSTRE. Metallic. FRACT. Hackly. H. 2·5-3. SP. GR. 12-20. OCCURRENCE. Occurs as the deposits of alluvial and placer type, derived from the disintegration and weathering of the primary gold bearing rocks. USE. An ore of Gold.

GOLD AMALGAM

COMP. Au with Hg and Ag. Gold with mercury and Silver. COM. FORM. Usually in grains, rarely in crystals. COLOUR. Yellowish white. STREAK. Yellowish white. CLEAV. Absent in grains, imperfect in crystals. LUSTRE. Metallic. FRACT. Hackly, H. 2·5-3. SP. GR. 8-8·2. OCCURRENCE. Occurs with mercury, silver and platinum.

SYLVANITE

COMP. (Au, Ag) Te_2. Telluride of gold and silver. CRYST. SYST. Monoclinic. COM. FORM. Massive or granular. COLOUR. Silver white to Steelgery. STREAK. Silver white. CLEAV. Perfect in crystals. LUSTRE. Metallic. FRACT. Brittle and uneven. H. 1·5-2, SP. GR. 8-8·2.

CALCIUM MINERALS

Calcium (Ca) does not occur in the free state in nature and it also occurs in combination with other elements as compounds. Calcium is procured from melted calcium chloride by decomposition by an electric current or by heating calcium iodide with sodium.

Calcium is considered as a metals, used as a redeer in the production of rare metals hard metals, alloys, etc. It is also used in the metallurgy of lead.

The chief calcium minerals are :

Carbonates	Calcite, $CaCO_3$
	Aragonite, $CaCO_3$
	Dolomite, $CaCO_3 . MgCO_3$
	Gaylussite, $Na_2CO_3 . CaCO_3$ $5H_2O$
	Barytocalcite, $BaCO_3 . CaCO_3$
Sulphates	Anhydrite, $CaSO_4$
	Gypsum, $CaSO_4 . 2H_2O$
	Glauberite, $Na_2SO_4 . CaSO_4$
	Polyhalite, $KSO_4 . MgSO_4 . 2CaSO_4 . 2H_2O$

Phosphate	Apatite, Ca_5 (F, Cl) $(PO_4)_3$
Fluoride	Fluor-spar, CaF_2
Borates	Ulexite, $NaCaB_5O_7 . 8H_2O$ Colemanite, $Ca_2B_6O_{11} . 5H_2O$
Silicates	Anorthite Feldspar, $CaAl_2Si_2O_8$ Pyroxene, Amphiboles, Garnets, Scapolites, Epidotes, Zeolites, Wallastonite. $CaSiO_3$

CALCITE

COMP. $CaCO_3$. Calcium Carbonate. CRYST. SYST. Hexagonal, COM. FORM. Crystals common, rhombohedral, Calcite type, sometimes massive. COLOUR. Colourless or white, sometimes red, brown, greyish, yellow, bluish, etc. STREAK. White, CLEAV. Perfect 3 sets, rhombohedral. LUSTRE. Vitreous to earthy, transparent to opaque. FRACT. Conchoidal. H. 3, scratched by knife. SP. GR. 2·71. OCCURRENCE. Calcite may be of chemical, either organic or inorganic origin. There are numerous occurrence of calcite in India, the more important ones are found in Andhra Pradesh, Gujarat, Rajasthan, Tamil Nadu and Punjab. VARIETIES. Iceland Spar, a colourless transparent variety ; Stain Spar, a compact finely fibrous variety with a satin like lustre. Dog-tooth Spar, crystals showing combination of flat prism, and scalenohedron ; Nailhead Spar, combination of prism and rhombohedron. USE. Used in the manufacture of bleaching powder, calcium carbide, paper, soap. paint, glass, etc. calcite powder is used as metal polish.

ARAGONITE

COMP. $CaCO_3$. Calcium Carbonate. CRYST. SYST. Orthorhombic. COM. FORM. Prisms, in globular, stalactitic, coraloidal or encrusting forms or massive. COLOUR. White, yellow, grey, violet and green. STREAK. White. CLEAV. Imperfect. LUSTRE. Vitreous. transparent. FRACT. Conchoidal, brittle. H. 3·5-4 SP. GR. 2·94.

DOLOMITE

COMP. $CaCO_3, MgCO_3$. Carbonate of calcium and magnesium. CRYST. SYST. Hexagonal. COM. FORM. Massive and granular.

COLOUR. white, brown, yellow, red, black and green. STREAK. White. CLEAV. Perfect. LUSTRE. Pearly, vitreous. FRACT. Conchoidal, uneven H. 3·5-4. SP. GR. 2·8-2·9. VARIETIES. Pearl Spar, Bitter Spar, Brown Spar, Rhomb Spar, Miemite, Ankerite. OCCURRENCE. Usually dolomite have been formed by the alteration of limestones and it also may be deposited from sea water. Dolomite occurs in beds at many geological horizons. It occurs at Jalpaiguri district in West Bengal, Chaibasa and Palamau in Bihar, Cuddapah and Kurnool in Andhra Pradesh, Jodhpur, Mewar and Kishengarh in Rajasthan. USE. Dolomite is used a a buffer for various metals. It is used in the ceramic industries for the manufacture of electric stores, insulators, glass for the electric bulbs, etc. It is also used as an important building material, for the manufacture of magnesia refractory brick, and a source of carbon dioxide.

ANHYDRITE

COMP. $CaSO_4$, Anhydrous calcium sulphate. CRYST. SYST. Orthorhombic. COM. FORM. Usually granular, fibrous, laminated, prismatic or tabular crystals. COLOUR. White or with bluish, reddish or greyish tint. STREAK. White. CLEAV. Perfect. LUSTRE. Pearly or vitreous. FRACT. Uneven. H. 3-3·5. SP. GR. 2·9 OCCURRENCE. Anhydrite occurs in association with gypsum as saline residue. USE. Anhydrite is used in the manufacture of plasters, cements, fertiliser, sulphates and sulphuric acid.

GYPSUM

COMP. $CaSO_4.\ 2H_2O$. Hydrated Calcium sulphate. CRYST. SYST. Monoclinic. COM. FORM. Usually crystals in prisms, fibrous, laminated or granular. COLOUR. Colourless or white or greyish, yellowish. STREAK. White. CLEAV. Perfect. LUSTRE. Pearly or silky or sub-vitreous. FRACT. Conchoidal. H. 1·5-2. SP. GR. 2·3. SP. PROP. Greasy feel. OCCURRENCE. Gypsum is formed as saline residue. dolomitisation of limestone in the sea and by the action of sulphuric acid, generated by the decomposition of pyrite. It occurs in Bikaner and Jodhpur in Rajasthan; in Coimbatore, Tiruchirapalli, Ramanathapuram and Tirunveli districts in Tamil Nadu, in Uttar Pradesh, in Gujarat, Himachal Pradesh of India. USE. Gypsum is used in the manufacture of fertiliser, cement, plaster of paris, ammonium sulphate, sulphuric acid, etc. *Selenite*, a transparent or translucent, *Gypsite*, a small crystals variety of Gypsum. *Satin Spar*, a fibrous variety of gypsum with a silky lustre and *Alabaster*; a fine grained, compact, light coloured or show white coloured massive variety of gypsum.

APATITE

COMP. $Ca_5F(PO_4)_3$ or $3Ca_3P_2O_8.CaF_2$; $Ca_5Cl(PO_4)_3$ or $3Ca_3P_2O_8.CaCl_2$. CRYST. SYST. Hexagonal. COM. FORM. Usually in crystals and in massive. COLOUR. White, yellow, pale green, bluish green, yellowish green. STREAK. White. LUSTRE. Vitreous to subvitreous. FRACT. Conchoidal, uneven, brittle. H. 5. SP. GR. 3·1-3·2. OCCURRENCE. Apatite occurs in igneous rocks and in small quantities in metamorphic rock. In India, apatite occurs in Bihar, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, and in Rajasthan. USE. Apatite is used for the manufacture of fertilizer and phosphorus chemicals.

FLUORITE, FLUOR-SPAR

COMP. CaF_2. Calcium Fluoride. CRYST. SYST. Isometric. COM. FORM. Usually occurs as crystals of cube, rarely as octahedra crystals and also occurs as granular. COLOUR. Colourless, white, green, pale violet, pale blue, amethyst. STREAK. White. CLEAV. Perfect, 3 sets, octahedral. LUSTRE. Vitreous. FRACT. Conchoidal, uneven or brittle. H. 4. SP. GR. 3·-3·2. OCCURRENCE. Fluorspar occurs in replacement deposits and hydrothermal veins in association with sphalerite, galena, barytes and quartz. In India fluorite occurs at Madhya Pradesh and Gujarat. USE. Fluorite is used in the manufacture of ornamental veses, opaque glasses, as a flux in steel making, ferro-alloys, artificial cryolite.

WOLLASTONITE, Tabular Spar.

COMP. $CaSiO_3$. Calcium metasilicate. CRYST. SYST. Triclinic or Monoclinic. COM. FORM. Tabular Crystals, also massive. fibrous, Columnar. COLOUR. White, grey, yellow, red, brown. STREAK. Uncoloured. CLEAV. Perfect. LUSTRE. Vitreous. FRACT. Even. H. 4·5-5. SP. GR. 2·8-2·9. OCCURRENCE. Occurs in limestones with diopside, etc.

STRONTIUM MINERALS

Strontium (Sr) does not occur in the free state in nature and it occurs in combination with other elements as compounds. Strontium (Sr) is procured from Strontium chloride by passing electric current through it.

The two commercial strontium minerals are Celestite (sulphate of strontium, $SrSo_4$) and Strontianite (Carbonate of strontium $SrCO_3$) occur as a gangue mineral in vein deposits with galena, barite and calcite of hydrothermal origin and as nodular deposits in sedimentary rocks associated with gypsum.

Strontium minerals are used for the manufacture fire works, beet sugar from the molasses, rail-road signals etc. It is also used for paints, waxes, electric batteries, for making glasses, rubber, glazes and enamels and is used in the steel furnaces.

CELESTITE

COMP. Sr SO_4, Strontium sulphate. CRYST SYST. Orthorhombic. COM. FORM. Tabular crystals, fibrous, massive, granular etc. COLOUR. white an pale blue tint in some varieties. STREAK. White. CLEAV. Perfect, parallel to the unit prism and basal pinacoid. LUSTRE. Vitreous, sometimes pearly, transparent to translucent. FRACT. Imperfectly conchoidal, very brittle. H. 3-3·5. SP. GR. 3·9 OCCURRENCE. occurs as a sedimentary deposit associated with gypsum, clay rock-salt, etc. It is found in Tiruchirapalli district, Uttatur and Karai. USE. Used as a source of strontium salts.

STRONTIANITE

COMP. Sr Co_3. Strontium carbonate. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic crystals, sometimes acicular and divergent, also in fibrous and granular. COLOUR. white, pale green, yellow grey, etc. STREAK. White. CLEAV. Nearly perfect LUSTRE. Vitrious to resinous. FRACT. Uneven, brittle H. 3·5-4. SP. GR. 3·6–3·7. SP. PROP. Effervesces with HCL. OCCURRENCE. Occurs as a vein deposit of hydrothermal origin in marls and limestone. USE. Used as a source of strontium salts.

BARIUM MINERALS

Barium (Ba) does not occur in the free state in nature. The metal barium is procured in the form of powder from barium chloride by passing electric current through it.

Barium Carbonate is used in ceramics or for barium peroxide. Barium is used to make lithopone, a brilliant white paint and is used as a 'gelter' inside electronic tubes to promote vacuum.

The chief barium minerals are :

Sulphates	Barytes, $BaSo_4$
Carbonates	Witherite, $BaCo_3$ Bromlite, (Ba,Ca) Co_3 Barytocalcite, $BaCo_3$. $CaCO_3$
Silicates	Celsian, $BaAl_2Si_2O_8$

BARYTE, BARYTES

COMP. $BaSO_4$, Barium sulphate, sometimes Calcium and strontium sulphate are present as impurities. CRYST. SYST. Orthorhombic. COM. FORM: Usually in crystals, also occurs as granular, lameller, massive, fibrous, columnar, etc. COLOUR. White, Colourless few with yellowish tint. STREAK. White. CLEAV. Perfect. LUSTRE. Vitreous, resinous, pearly. FRACT. Uneven, brittle. H. 3–3·5. SP. GR. 4·5. OCCURRENCE. Baryte deposits are found to occur as veins and replacements deposits. It is also occur as gangue minerals with galena, Zinc blende, fluorite and quartz. In India it is found in Andhra Pradesh, Rajasthan, Himachal Pradesh, West Bengal, Bihar, Madhya Pradesh and Punjab. USE. Used in the manufacture of white paint.

WITHERITE

COMP. $BaCo_3$. Barium Carbonate. CRYST. SYST. Orthorhombic. COM. FORM. Crystals common, also occurs massive granular, columnar. COLOUR. White. STREAK. White. CLEAV. Imperfect. LUSTRE. Vitreous and resinous. FRACT. Uneven; brittle. H. 3·5. SP. GR. 4·3. OCCURRENCE. Occurs as vein deposits. as gangue minerals associated with galena and barytes. USE. Used as a source of barium salts and in Ceramic industry.

RADIUM MINERALS

Radium is a disintegration product of Uranium and is one of the radioactive element. Radium occurs in minute quantity in Uranium minerals. The Radium salts resemble those barium in their physical and chemical properties. Radium salts are used in the manufacture of yellow and brown glass and glazes, for alloys of steel, nickel and copper. It is also used for atomic energy. They are described with Uranium minerals.

BERYLLIUM MINERALS

Beryllium is a very light metal. It is also known as a radioactive element. It is used as alloys with copper and nickel, in X-ray tubes, fluorescent lamps and neon lamps. The Beryllium Oxide is used as a refractory.

Beryllium minerals occur as an accessory minerals in acid igneous rocks, such as granites and pegmatites, in metamorphic rocks and in alluvial deposits.

The important beryllium minerals are:

Silicate	Beryl, $Be_3Al_2Si_6O_{18}$
Aluminate	Chrysoberyl, $BeAl_2O_4$

BERYL

COMP. $Be_3Al_2Si_6O_{18}$. Sillicate of beryllium and aluminium. CRYST. SYST. Hexagonal. COM. FORM. Crystals Common, also found massive, crystalline. COLOUR. Yellow, white, pale green, blue, STRIKE. White. LUSTRE. Vitreous and resinous CLEAV. Imperfect. FRACT. Conchoidal or uneven, brittle. H. 7·5–8. SP. GR. 2·7. OCCURRENCE. Beryl occurs as an accessory mineral in acid igneous rocks such as pegmatities and granites. In India, Beryl occurs in Mewar, Jodhpur and Ajmer in Rajasthan, Hazaribagh, Gaya and Monghyr in Bihar and Andhra Pradesh. USE. Used as alloys with copper, iron and nickel. Emerald green or pale green variety, known as *Emerald* and pale blue variety, known as *Aquamarine*, used as gem stones.

CHRYSOBERYL

COMP. $BeAl_2O_4$. Beryllium aluminate. COM. FORM. Prismatic Crystals. COLOUR. White with shades of green. STREAK. Uncoloured. CLEAV. Imperfect. LUSTRE. Vitreous, transparent and translucent. FRACT. Conchoidal, uneven. H. 8·5. SP. GR. 3·6–3·6. OCCURRENCE. Chrysoberyl occur in alluvial deposits, igneous and metamorphic rocks. The green variety chrysoberyl is known as *Alexandrite* is used as gem.

MAGNESIUM MINERALS

Magnesium (Mg) does not occur in the free state in nature. It is artificially prepared by electrolysis of a mixture of anhydrous magnesium chloride and sodium or potassium chloride. Magnesium is the lightest metal known, is fairly strong metal, is silver white in colour, and easily tarnishing to the magnesium oxide, MgO.

Magnesium is used for making alloys with aluminium and zinc, and these alloys are used in airplanes, automobiles and other materials requiring lightness. It is also used for making alloys with beryllium. It is used for cameras, surveying instruments, musical instruments, radio-diaphragm, etc.

The chief magnesium minerals are :

Silicates	Biotite, K $(Mg, Fe)_3$ $(AlSi_3)$. Pyroxene, $MgSiO_3$. Amphibole, $Mg_7Si_8O_{22}(OH)_2$ Olivine, Mg_2SiO_4.
Oxides	Periclase, MgO. Brucite, $Mg(OH)_2$.
Carbonates	Magnesite, $MgCO_3$. Dolomite, $MgCo_3$. $CaCO_3$. (Described with calcium minerals)
Sulphates	Epsomite, $MgSO_4$. $7H_2O$. Kieserite, $MgSO_4$. H_2O. Polyhalite, $MgSO_4$. K_2SO_4. $2CaSO_4$. $2H_2O$. Kainite, $MgSO_4$. KCL. $3H_2O$.
Chloride ..	Carnallite, $MgCl_2$. KCL. $6H_2O$.
Borate and Chloride ..	Boracite, 5MgO. $MgCl_2$. $7B_2O_3$.
Aluminate ..	Spinel, $MgAl_2O_4$.
Hydrous Silicates	Talc, $Mg_3Si_4O_{10}(OH)_2$ Serpentine, $Mg_6Si_4O_{10}(OH)_2$. Meerchaum, $Mg_2Si_3O_6(OH)_4$.

BRUCITE

COMP. $Mg(OH)_2$. Hydrous oxide of magnesium. CRYST. SYST. Hexagonal. COM. FORM. Prismatic and tabular crystals, rhombohedral, usually massive, sometimes fibrous. COLOUR. White, bluish, greyish, greenish, etc. STREAK. White. CLEAV. Perfect. LUSTRE. Pearly, fibrous, silky. FRACT. H. 2·5. SP, GR, 2·39, OCCURRENCE. Brucite is found in contact-metamorphosed impure limestones.

MAGNESITE

COMP. $MgCO_3$. Magnesium Carbonate. CRYST. SYST. Hexagonal, rhombohedral. COM. FORM. Usually massive, fibrous, sometimes granular, crystals rare. COLOUR. White chalk like, greyish-white, yellowish, brown. STREAK. White. LUSTRE. Vitreous, earthy, dull. CLEAV. Perfect in crystals. FRACT. Conchoidal, flat. H. 3·5–4·5. SP. GR. 2·8–3, OCCURRENCE, Occur as irregular veins and fracture-zones in serpentine masses. USE. Used for refractory bricks, in the production of Carbon dioxide, furnace linings, for the production of magnesium and magnesium salts.

EPSOMITE (Epsom Salt)

COMP. $MgSO_4 . 7H_2O$. Hydrated magnesium sulphate. CRYST. SYST. Orthorhombic. COM. FORM. Usually botryoidal, fibrous crusts and rerely prismatic crystals. COLOUR. White. STREAK. White. CLEAV. Imperfect. LUSTRE. Vitreous, transparent to translucent. H. 2–2·5. SP. GR. 1·68. SP. PROP. Saline and bitter taste. OCCURRENCE. Epsomite occurs in mineral waters, in sea-water, in saline lakes etc. USE. Used in tanning and in medicine.

TALC

COMP. $Mg_3Si_4O_{10}(OH)_2$. Hydrous magnesium silicate. CRYST. SYST. Orthorhombic or monoclinic. COM. FORM. Usually foliated massive, also granular, massive, tabular rarely in crystals. COLOUR. Silvery white, white, apple green, grey, dark green. STREAK. White, light green. CLEAV. Perfect basal, thin laminae flexible, not elastic. LUSTRE. Pearly. FRACT Even. H. 1. SP. GR. 2·7–2·8, SP, PROP, Greasy feel. VARIETIES. *Steatite*, *Soapstone*, a grey or white coloured with various shades, massive variety of talc. *Pot-stone,* impure soapstone, impure talc; *Rensselarite,* pseudomorphous fibrous, fine to coarse, altered from pyroxene and tremolite. *French Chalk,* milk white coloured talc with pearly lustre, *Indurated talc,* is a impure slaty talc. OCCURRENCE. Occurs in the metamorphic rocks such as talc schists, and steatite, as a secondary mineral resulting from the hydration of magnesium-bearing rocks. USE. Used for toilet powder leather making, in plasters, for crayons, for paints, papers, rubber,etc.

SERPENTINE

COMP. $Mg_6Si_4O_{10}(OH)_8$. Hydrous magnesium silicate. CRYST. SYST. Monoclinic. COM. FORM. Usually massive, foliated, granular, fibrous, crystals rare. COLOUR. Green and different shades of green. blackish green, brownish red, brownish yellow. STREAK. Slightly shinning white. CLEAV. Imperfect. LUSTRE.

Subresinous, pearly, earthy, waxlike. FRACT. Conchoidal. H. 3–4 rarely 5. SP. GR. 2·5–2·6. VARIETIES. *Precious or noble Serpentine,* oil green colour with shades, *Antigorite,* thin lameller variety, *Chrysotile,* delicately fibrous variety, *Picrolite,* a columnar, flexible or fibrous variety, *Bastite, Schillerspar,* altered variety of enstatite, *Ophicalcite,* a serpentine rock, mixed with calcite, magnesite and dolomite. OCCURRENCE. Serpentine occurs in peridotites, dunites, picrites, etc. USE. Use in internal architectural decoration. Ornamental work and as a building stone.

ZINC MINERALS

Zinc (Zn) is a bluish white brittle metal. It is generally occurs in association with other elements as compounds, and rarely occurs as native state. It is found in veins in association with galena, pyrites, chalcopyrite and other sulphide minerals. Zinc is obtained from its ores by roasting and calcining the ores first and then by heating in retorts at a high temperature with coal or coke. The Zinc Oxide is reduced to the metal.

The Chief mode of occurrences of Zinc ores are as contact metasomatic replacement and as disseminations. Zinc ores occurs as cavity fillings, bands and lenses in crystalline limestone. Most Zinc ores occur as cavity fillings and replacements formed by low temperature hydrothermal solutions.

Zinc is used for coating, galvanising in the manufacture of alloys with other metals, in the manufacture of tubes like toothpaste tubes, as pigments, in soldering, in dyeing, glue-making and in preventing decay in wood.

The important Zinc minerals are:

Element	..	..	Native Zinc (rare).
Oxides	..	..	Zincite, ZnO. Franklinite, (Fe, Zn, Mn) (Fe, Mn) $_2O_4$.
Sulphide	..	..	Sphalerite (Zincblende), ZnS.
Carbonate	..	..	Smithsonite, $ZnCO_3$. Hydrozincite, $2ZnCO_3$. $3Zn(OH)_2$.
Silicates	..	..	Willemite, Zn_2SiO_4. Hemimorphite, $Zn_4Si_2O_7(OH)_2$. H_2O.
Sulphate	..	..	Goslarite, $ZnSO_4$ $7H_2O$.

ZINCITE (Red Oxide of Zinc, Spartalite)

COMP. ZnO. Zinc Oxide. Usually associated with manganese. CRYST. SYST. Hexagonal. COM. FORM. Usually massive, foliaceous, granular, crystal rare hemimorphic. COLOUR. Deep red. STRIKE. Orange-yellow. CLEAV. Perfect, basal. LUSTRE. Sub-adamantine and sub-translucent. FRACT. Sub-conchoidal, brittle. H. 4–4·5. SP. GR. 5·7. OCCURRENCE, Occurs as bands and lenses in crystalline dolomitic limestone with Calcite, Franklinite, Willemnite, etc.

FRANKLINITE

COMP. $(Fe, Zn, Mn)\ (Fe, Mn)_2O_4$. Oxide of iron, Zinc and manganese. CRYST. SYST. Isometric. COM. FORM. Crystals in octahedra, often in rounded grains and massive. COLOUR. Black. STREAK. Black. CLEAV. Imperfect. LUSTRE. Metallic, FRACT. Uneven, brittle. H. 5·5–6·5. SP. GR, 5–5·2. OCCURRENCE. Occurs as bands and lenses in crystalline limestone with Calcite, Willemite and Zincite.

SPHALERITE, ZINC BLENDE (Black Jack)

COMP. ZnS. Zinc sulphide. CRYST. SYST. Isometric. COM. FORM. Crystals common, tetrahedral and rhombdoolecahedra, occasionally massive, compact, botryoidal or fibrous. COLOUR. Black, brown, yellow, etc. STREAK. Reddish brown to brownish yellow. CLEAV. Perfect in crystals (6 sets). LUSTRE. Resinous to adamantine. FRACT. Conchoidal. H. 3·5–4. SP. GR. 3·9–4·2. OCCURRENCE. Occurs in veins in association with galena, chalcopyrite, iron pyrite and other sulphide ores. It occurs in Rajasthan, Tamil Nadu, Jammu & Kashmir, Sikkim, Karnataka of India.

SMITHSONITE (Calamine)

COMP. $ZnCO_3$. Zinc Carbonate. CRYST. SYST. Hexagonal. COM. FORM. Commonly massive, granular, reniform, botryoidal, crystals, rhombohedra rare. COLOUR. White, greyish, greenish, brownish white. STREAK. White. CLEAV. Perfect. LUSTRE, Vitreous to pearly. FRACT. Uneven, Brittle. H. 5·5. SP. GR. 4–4·5. OCCURRENCE. Occurs in veins and in beds associated with Sphalerite, galena, iron and copper ores and in considered as mostly of secondary origin.

WILLEMNITE

COMP. Zn_2SiO_4. Zinc Silicate. CRYST. SYST. Hexagonal. COM. FORM. Prismatic crystals, rhombohedral also massive.

COLOUR. Yellow, green, brown. STREAK. Yellowish or greenish. LUSTRE. Vitreous or resinous. CLEAV. Imperfect. H. 5–5·5, SP. GR. 4–4·1. OCCURRENCE. Occurs as lenses and bands in limestones with zincite, franklinite, etc.

GOSLARITE

COMP. $ZnSO_4 . 7H_2O$. Hydrated zinc sulphate. CRYST. SYST. Orthorhombic. COM. FORM. Usually encrusting and stalactitic, also prismatic crystals. COLOUR. White. STREAK. White. CLEAV. Perfect in crystal. LUSTRE. Vitreous. H. 2·25, SP. GR. 2·1. OCCURRENCE. Results from the decomposion of Sphalerite.

CADMIUM MINERALS

Cadmium (Cd) is a bluish white metal and is of rare occurrence. It occurs usually in association with sphalerite and is obtained as a by-product during the smelting of zinc ores. Cadmium is used in the manufacture of alloys, Cadmium salts, etc.

The only Cadminium minerals is

Sulphide	Greenockite. CdS.

GREENOCKITE

COMP. CdS. Cadmium sulphide, CRYST. SYST. Hexagonal. COM. FORM. Often as Crystals, hemimorphic. COLOUR. Orange-yellow, citron or honey. STREAK. Orange-yellow, brick red. CLEAV. Imperfect. LUSTRE. Resinous, adamantine. FRACT. Uneven. H. 3–3·5. SP. GR. 5. OCCURENCE. Occurs associated with Zinc ore minerals as a coating on Zinc ores.

MERCURY MINERALS

Mercury (Hg) often occurs in native state. The commercial important minerals are Cinnabar (HgS) and Calomel (Hg_2Cl_2). It is a silver white metal, liquid at ordinary temperature and boils at 357°c. Mercury usually obtained from Cinnabar by roasting it in oxidising atmosphere. During roasting sulphur is oxidised to sulphurous acid and mercury comes out in a volatile state and condensed.

Mercury occurs as stockworks, dissemination and impregnations in any kind of rocks. It is deposited by hot springs in volcanic areas. It occurs in small quantity in gold quartz veins. The mercury deposits are formed by hydrothermal solutions at low temperature. In India, Quilon in Kerala, Bhandara district in Madhya Pradesh and few traces of Cinnabar are found to occur in Assam and Kashmir

The important mercury minerals are:

Element	Native Mercury, Hg.
Amalgam	Native Amalgam $Hg_x Ag$.
Sulphide	Cinnabar, HgS.
Chloride	Calomel, Hg_2Cl_2.

NATIVE MERCURY, QUICKSILVER

COMP. Hg. Pure mercury a small amount of silver may present CRYST. SYST. Isometric, Crystallises when frozen. COM. FORM Small fluid globules, Crystals showing a rhombohedral structure by X-rays. COLOUR. Tin white. LUSTRE. Metallic, Opaque. SP. GR. 13·5. OCCURRENCE. Occurs as a rare mineral and is of secondary origin. It occurs as fluid globules scattered through Cinnabar. It is deposited with Cinnabar from the waters of certain hot springs.

NATIVE AMALGAM. SILVER AMALGAM

COMP. Mercury (Hg) and silver (Ag) in varying proportions. CRYST. SYST. Isometric. COM. FORM, Occurs as massive and in Crystals in rhombdodecahedron. COLOUR. Silver white. STREAK. Silver white. LUSTRE. Metallic, Opaque. CLEAV. Perfect in crystals. FRACT, Conchoidal, Uneven, brittle, H. 3–3·5. SP. GR. 10·5–13·9. OCCURRENCE. Occurs as scattered grains.

CINNABAR

COMP. HgS. Mercury sulphide, contains clay, bitumen as impurities. CRYST. SYST. Hexagonal. COM. FORM. Commonly massive, granular and crusts, prismatic and tabular crystals. COLOUR. Cochineal-red. STREAK. Scarlet. CLEAV. Perfect in prismatic crystals. LUSTRE. Usually dull when massive and admantine in crystals. FRACT. Sub-conchoidal or Uneven. H. 2–2·5. SP. GR. 8·1, VARIETY. A liver-brown colour Cinnabar is *Hepatic Cinnabar*. OCCURRENCE. Occurs as stockworks, dissemination and impregnations in any kind of rocks. It is deposited by hot springs in Volcanic areas. USE. Most important source of mercury.

CALOMEL, HORN QUICK SILVER

COMP. Hg_2Cl_2. Mercury chloride. CRYST. SYST. Tetragonal. COM. FORM. Tabular and pyramidal crystals. COLOUR, White, yellowish, greyish, brownish. STREAK. Pale yellowish

white. CLEAV. Perfect. LUSTRE. Adamantine. FRACT. Conchoidal. H. 1–2. SP. GR. 6·48. OCCURRENCE. Occurs in association with Cinnabar and occurs commonly as a coating of minute crystals upon other minerals.

BORON MINERALS

Boron minerals does not occur in a free state in nature and few occur as compounds. Boron may be produced by reduction of boric acid. The Boron minerals occur as deposits from volcanic emanations and from the waters of hot springs of volcanic areas and as a result of the drying up of enclosed bodies of water. Boron minerals are used for the manufacture of glasses, enamels, pottery, enamelled iron, artificial gem-stones, soap, glue and are used in cloth and tanning industries.

The Chief boron minerals are :

Silicates	Tourmaline, NaCa, $MgFe_3Al_3$, $[(AlSi)_3O_9]$ $[(OH, F^3)_4]$ Axinite, $H(Ca, Fe, Mn)_3 Al_2B(SiO_4)_4$. Datolite, $HCaBSiO_5$
Boric acid	Sassoline, H_3BO_3 or $3H_2O.\ B_2O_3$.
Hydrated Sodium Borates	Borax, $Na_2B_4O_7.\ 10H_2O$ or $Na_2O.\ 2B_2O_3.\ 10H_2O$. Kernite, $Na_2O.\ 2B_2O_3.\ 4H_2O$
Hydrated Calcium Borates	Colemanite, $Ca_2B_6O_{11}.\ 5H_2O$ or $2CaO.\ 3B_2O_3.\ 5H_2O$.
Hydrated Sodium Calcium Borate	Ulexite. $NaCaB_5O_9.\ 8H_2O$ or $Na_2O.\ 2CaO.\ 5B_2O_3.\ 16H_2O$.
Magnesium Borate and Chloride	Boracite, $5MgO.\ MgCl_2.\ 7B_2O_3$.

SASSOLINE, NATIVE BORIC ACID

COMP. Boric acid, H_3BO_3, or $3H_2O.\ B_2O_3$. CRYST. SYST. Triclinc. COM. FORM. Commonly scales (glistening), crystals rare, prismatic. COLOUR. White, grey or yellow. STREAK. White,

CLEAV. Perfect basal. LUSTRE. Pearly. H. 1. SP. GR. 1·4. SP. PROP. Saline and bitter taste, smooth and unctuous feel, Sectile and flexible tenacity. OCCURRENCE. Occurs with sulphur in the crater of Volcano and also found around fumaroles.

KERNITE (Rasorite)

COMP. Na_2O. $2B_2O_3$. $4H_2O$. Hydrated sodium borate. CRYST. SYST. Monoclinic. COM. FORM. Massive. COLOUR. White, STREAK. White. CLEAV. Perfect, parallel to the basal pinacoid and to the Orthopinacoid. LUSTRE. Pearly to Vitreous, transparent to transluscent. H. 3. SP. GR. 1·95. OCCURRENCE, Kernite is now the most important source of industrial borates.

COLEMANITE

COMP. $Ca_2B_6O_{11}$. $5H_2O$. or $2CaO$. $3B_2O_3$. $5H_2O$. CRYST. SYST. Monoclinic. COM. FORM.. Massive, Crystalline, granular and prismatic crystals. COLOUR. Colourless, white or greyish. STREAK. White. CLEAV. Perfect, parallel to clino pinacoid. LUSTRE. Vitreous to adamantine, transparent to translucent. FRACT. Hackly. H. 4–4·5. SP. GR. 2·42. OCCURRENCE. Occurs as nodules in clays and the deposits results from the leaching of ulexite beds by sodium Chloride solutions.

ULEXITE

COMP. $NaCaB_5O_9$. $8H_2O$. or Na_2O. $2CaO$. $5B_2O_3$, $16H_2O$, Hydrated sodium calcium borate. CRYST. SYST. Monoclinic. COM. FORM. Globular, reniform and fibrous structure. COLOUR. White. STREAK. White. CLEAV. Imperfect. LUSTRE. Silky, Opaque. H.1. SP. GR. 1·65. OCCURRENCE, Ulexite occurs associated with borax in lake deposits and associated with gypsum and rock salt in lagoon deposits.

BORACITE

COMP. $5MgO$. $MgCl_2$. $7B_2O_3$. Borate and chloride of magnesium. CRYST. SYST. Isometric. COM. FORM. Cubic and Octahedral Crystals, massive, granular and Columnar. COLOUR. Colourless, white, yellow, greenish or greyish. STREAK. White. CLEAV. Imperfect. LUSTRE. Vitreous. FRACT. Uneven, Conchoidal, brittle. H. 7. SP. GR. 2·95. OCCURRENCE. Boracite occurs in saline deposits associated with rock-salt, gypsum and anhydrite.

AXINITE

COMP. H $(Ca,Fe,Mn)_3$ $Al_2B(SiO_4)_4$. Boro- silicate of aluminium and calcium. CRYST. SYST. Triclinic. COM. FORM. Usually thin crystals, also massive or lameller. COLOUR. Brown, clove brown, blue, grey. STREAK. Uncoloured. CLEAV. Perfect. LUSTRE. Vitreous. FRACT. Conchoidal, brittle. H. 6·5–7. SP. GR. 3·27. OCCURRENCE. Occurs in lime rich rocks in contact with igneous rocks.

ALUMINIUM MINERALS

Aluminium (Al) does not occur in a free state in nature, occur as compounds in the earth crust and is the most abundant of metals. It is a silver white metal, capable of taking a high polish. The metal is produced in the electric furnace by reduction of alumina obtained from bauxite. Due to its lightness, the metal is important for the manufacture of many articles. Aluminium minerals occurs as segregated sheets and lenses in horizontal masses of laterite in tropical and sub-tropical countries. Laterite occurs as cappings on extensive plateaus and flat topped hills or on peneplained surfaces. Aluminium is used for the manufacture of utensils, for wrapping-material and foil and in the canning industry, etc.

The important aluminium minerals are :

Silicates	Feldspars	Orthoclase, $KAlSi_3O_8$
		Albite, $NaAlSi_3O_8$
		Anorthite, $CaAl_2Si_2O_8$
		Celsian, $BaAl_2Si_2O_8$
	Micas	Muscovite, $KAl_2(AlS_3)O_{10}(OH,F)_2$
		Biotite, $K(Mg, Fe)_3$ $(AlSi_3)O_{10}.(OH, F)_2$
		Lepidolite. $KLi_2Al(Si_4O_{10})(OH,F)_2$
		Phlogopite, $H_2KMg_3Al(SiO_4)_3$
Silicates	..	Andalusite, Al_2SiO_5
		Sillimanite, Al_2SiO_5
		Kyanite, Al_2SiO_5
		Staurolite, $FeAl_4Si_2O_{10}(OH_2)$
		Tourmaline, (Na, Ca) (Mg. Fe or Li$)_3$ B_3Al_3
		Cordierite, $(Mg, Fe)_2$ $Al_3(AlSi_5)O_{18}.H_2O$
		Mullite, $Al_6Si_2O_{13}$

OCCURRENCE. Occurs in veins and found in clays of Tertiary age.

ALUM, ALUMNITE.

COMP. $KAl(SO_4)_2$. $12H_2O$. Hydrated aluminium potassium sulphate. CRYST. SYST. Isometric. COM. FORM. Octahedra and rhombohedrons. massive COLOUR. Colourless, white. STREAK. White. CLEAV. Imperfect. LUSTRE. Vitreous. FRACT. Conchoidal, uneven, britte. H. 2–2·5. SP. GR. 1·75, SP. PROP. Readily soluble in water. OCCURRENCE. Occurs on shales known as alum shales, in the neighbourhood of volcanoes.

CRYOLITE

COMP. Na_3AlF_6. or $3NaF$. AlF_3. A fluoride of sodium and aluminium. CRYST. SYST. Monoclinic. COM. FORM. Massive, crystals rare. COLOUR. White. colourless, snow-white, reddish, brownish, black, brick-red. STREAK. Usually white. CLEAV. Perfect, parallel to the basal pinacoid, prism and orthodome. LUSTRE. Vitreous, transparent to translucent. FRACT. Uneven, bittle. H. 2·5. SP. GR. 2·95–3·0. SP. PROP. Invisible when immersed in water. OCCURRENCE. Occurs in veins in granite and associated with sphalerite, galena, fluorite, siderite, etc. USES. In manufacture of aluminium, white porcelain glass, sodium and aluminium salts.

TURQUOISE

COMP. CuO. $3Al_2O_3$. $2P_2O_6$. $9H_2O$. Hydrous phosphate of aluminium. CRYST. SYST. Triclinic. COM. FORM. Massive, reniform, encrusting or stalactitic. COLOUR. Sky-blue, bluish green to apple green and greenish grey. STREAK. White or greenish. CLEAV. Absent in massive material, in crystals in two directions. LUSTRE. Waxy, feeble. FRACT. Conchoidal. H. 6. SP. GR. 2·6-2·83. OCCURRENCE. Occurs in thin veins ; narrow seams or in irregular patches in igneous rocks such as trachyte. USES. As an ornamental materials, teeth, fossil bones, etc.

WAVELLITE

COMP. $4AlPO_4$. $2Al(OH)_3$. $9H_2O$. Hydrated phosphate of aluminium. CRYST. SYST. Orthorhombic. COM. FORM, Usually in aggregates, globular, crystalline, radiated structure and in crystals rare. COLOUR. White, yellow, grey, green, brown, black. STREAK. White. CLEAV. Rather perfect. LUSTRE. Vitreous

and translucent. FRACT. Uneven or sub-conchoidal. H. 3·5–4. SP. GR. 2·3. OCCURRENCE. Occurs in residual deposits formed from igneous rocks and also occurs as nodular masses with manganese ores, limonite, etc.

ANDALUSITE

COMP. Al_2SiO_5. Aluminium silicate. CRYST. SYST. Orthorhombic. COM. FORM. Usually prismatic square crystals, also massive, columnar, radiating and granular. COLOUR. Rose-red, flesh-red, white, pearl grey, reddish brown, olive-green. STREAK. Uncoloured. CLEAV. Imperfect, sometimes perfect in crystals. LUSTRE. Vitreous, transparent to opaque. FRACT. Uneven, sub-conchoidal. H. 7·5. SP. GR. 3·1–3·2. VARIETY : *Chiastolite* or *Macle,* found in stout crystals with tessellated markings due to carbonaceous impurities; *Viridine* or *Manganandalusite,* a green coloured, iron and manganese containing variety of andalusite. OCCURRENCE. Occurs in metamorphic rocks such as andalusite-hornfels.

SILLIMANITE

COMP. Al_2SiO_5. Aluminium silicate. CRYST. SYST. Orthorhombic. COM. FORM. Usually long slender or needle shaped radiating crystals, also massive fibrous. COLOUR. White, brown, grey, green. STREAK. Colourless. CLEAV. Perfect. LUSTRE. Vitreous to sub-admantine. FRACT. Uneven. H. 6–7. SP. GR. 3·23–3·24. OCCURRENCE. Occurs in metamorphic rocks.

KYANITE, Cyanite, Disthene.

COMP. Al_2SiO_5. Aluminium silicate. CRYST. SYST. Triclinic COM. FORM. Usually blade like crystals, columnar to subfibrous. COLOUR. Blue, white, grey. STREAK. White or uncoloured. CLEAV. Perfect, parallel to pinacoid. LUSTRE. Vitreous to pearly. FRACT. Uneven. H. varies from 4–7·5 on different faces. SP. GR. 3·6–3·7. OCCURRENCE. Occurs in metamorphic rocks, Kyanite-gneisses and schists.

TOURMALINE, Turmalin

COMP. $(Na, Ca)\ (Mg, Fe\ or\ Li)\ B_3\ [(Al, Si)_3\ O_9]_3\ (OH, F)_4$. Complex silicate of boron and aluminium with iron or magnesium or alkali metals. CRYST. SYST. Hexagonal, rhombohedral-hemimor-

phic. COM. FORM. Prismatic crystals, slender to acicular, also massive COLOUR. Black, bluish black, blue, green, red. STREAK. Uncoloured. CLEAV. Imperfect, rhombohedral. LUSTRE. Vitreous transparent to opaque. FRACT. Uneven to sub-conchoidal. M. 7–7·5. SP. GR. 2·98–2·30. VARIETY. *Rubellite,* red or pink coloured tourmaline; *Brazilian Sapphire,* Berlin-blue variety, *Brazilian Emerald,* transparent green variety, *peridot of Ceylon,* honey-yellow coloured; *Schorl,* black coloured; *Achroite,* colourless tourmaline; *Aphrizite,* black variety; *Indicolite,* indigo variety.

STAUROLITE

COMP. $Ca_{10}Al_4(Mg, Fe)_2\ (Si_2O_7)_2\ (SiO_4)_5\ (OH)_4$. Silicate of calcium, aluminium and magnesium with iron. CRYST. SYST. Tetragonal. COM. FORM. Prismatic crystals, twins cruciform, also massive. COLOUR. Dark reddish, brown, brownish black, yellow. STREAK. Uncoloured or white or greyish. CLEAV. Perfect, but interrupted. LUSTRE. Vitreous to resinous. FRACT, Conchoidal, H. 7–7·5. SP. GR. 3·7. OCCURRENCE. Occurs in metamorphic rocks, such as staurolite schists and gneisses, associated with garnet and kyanite.

CORDIERITE. Iolite, Diehroite.

COMP. $(Mg, Fe)_2\ Al_4Si_5O_{18}H_2O$. Silicate of aluminium, magnesium, iron with water. CRYST. SYST. Orthorhombic. COM. FORM. Short prismatic crystals, also massive, granular and compact. COLOUR. Light to dark blue, smoky blue with various shades. STREAK. Uncoloured. CLEAV. Imperfect. LUSTRE. Vitreous. FRACT. Subconchoidal; brittle. H. 7–7·5. SP. GR. 2·6–7·7, OCCURRENCE. Occurs in metamorphic rocks such as cordierite-gneisses, cordierite-hornfels. USE. Used as a gemstone.

TOPAZ

COMP. $(AlF)_2\,SiO_4$. Fluo-silicate of aluminium. CRYST. SYST. Tetragonal. COM. FORM. Prismatic crystals, twins cruciform, also columnar or granular. COLOUR. Yellow, straw-yellow, wine yellow, white, grey, green, blue, red. STREAK. Uncoloured. LUSTRE. Vitreous. FRACT. Subconchoidal to uneven. H. 8, SP. GR. 3·45–3·60. OCCURRENCE. Occurs in acid igneous rocks such as granites, such as granites, pegmatites, rhyolites, etc. USE. Used as a gemstone.

TITANIUM MINERALS

Titanium (Ti) does not occur in free state in nature and occur as compounds in the earth crust. It is a greyish coloured metal and it resembles tin in its chemical properties. Titanium minerals occur as accessory constituents in the igneous rocks such as anorthosites, granites, syenites, pegmatites, diorites and in the metamorphic rocks such as gneisses, slates, phyllites, amphibolites, etc. Ilmenite (FeO. TiO_2) occurs as impurity in magnetite. Titanium minerals occur associated monazite and zircon. They occur as placer deposits, magmatic deposits and disseminated replacement deposits. Titanium minerals are found in Bihar, Rajasthan, Orissa, Karnataka, Kerala, Tamil Nadu, and Maharastra. Titanium minerals are used for making ferrous and non-ferrous alloys, pigment, paints, cutting tools, in the ceramic industry.

The important minerals are:

Oxides	Rutile,	TiO_2
	Anatase.	TiO_2
	Brookite,	TiO_2
	Ilmenite.	FeO. TiO
	Sphene,	$CaTiSiO_5$

RUTILE

COMP. TiO_2. Titanium dioxide. CRYST. SYST. Tetragonal. COM. FORM. Often crystals in tetragonal prisms and acicular and in needles form. COLOUR. Reddish-brown, yellowish, red, black or red. STREAK. Pale brown. CLEAV. Imperfect. LUSTRE. Metallic, admantine. FRACT. Subconchoidal, brittle. H. 6–6·5; SP. GR. 4·2. OCCURRENCE. Occurs as an accessory minerals of igneous rocks and as an important constituent of beach sands resulting from the denudation of rutile-bearing rocks of India.

ANATASE, Octahedrite

COMP. TiO_2. Titanium dioxide. CRYST. SYST. Tetragonal. COM. FORM. Prismatic or tabular crystals. COLOUR. Brown, indigo-blue, black. STREAK. Colourless. CLEAV. Perfect, basal and piramid. LUSTRE. Adamantine, transparent or Opaque FRACT. Uneven. H. 5–5·6. SP. GR. 3·8–3·9, OCCURRENCE. Occur as an alteration product of other titanium bearing minerals and also formed in veins of hydrothermal origin.

BROOKITE

COMP. TiO_2. Titanium Oxide. CRYST. SYST. Orthorhombic. COM. FORM. Tabular crystals. COLOUR. Brown, black, reddish. STREAK. Colourless. CLEAV. Perfect. LUSTRE. Adamantine. FRACT. Subconchoidal to uneven, brittle. H. 5–5·6. SP. GR. 4. OCCURRENCE. Occurs as an alteration product of other titanium-bearing minerals.

ILMENITE

COMP. FeO. TiO_2. Oxide of iron and titanium. CRYST. SYST, Hexagonal. COM. FORM. Usually massive and as sand also found as scales or plates. COLOUR. Iron-black,. STREAK. Black to brownish-black. CLEAV. Imperfect. LUSTRE. Metallic. FRACT. Conchoidal. H. 5–6. SP. GR. 4·5–5, OCCURRENCE, Occurs as an accessory constituent in gabbros, norites and other basic igneous rocks and also occurs in dyke-like bodies derived from magmatic segregations.

TITANITE, Sphene

COMP. $CaTiSiO_5$. Calcium titano silicate. CRYST. SYST. Monoclinic. COM. FORM. Prismatic crystals, massive and rarely lameller. COLOUR. Green, yellow, brown, red, grey and black. STREAK. White or slightly greenish. CLEAV. Imperfect. LUSTRE. Resinous or adamantine. FRACT. Conchoidal. H. 5–5·5. SP. GR. 3·4–3·5. OCCURRENCE. Occurs as an accessory mineral in associated with pyroxene, amphibole, chlorite, apatite, scapolite, zircon, etc.

ZIRCONIUM MINERALS

Zirconium (Zr.) does not occur free in nature. Zircon occurs as an accessory mineral of acid igneous rocks such as granite, syenite, pegmatite, in metamorphic rocks, such as marbles, gneisses, etc. and in sedimentary rocks such as sandstone. Zircon associated with ilmenite, rutile and monazite occurs as beach sands. In India, Zirconium ore minerals are found in beach sands of Quilon and Travancore in Kerala, Manavalakurichi in Tamil Nadu, Tanjore, Visakhapatnam, Kanyakumari, Tiruneveli, Ramanathapuram of South India. Zircon is used for manufacturing alloys with silcon,

iron, tungsten, etc. also used as a refractory and as a gemstone, in abrasives, in enamels, for X-Ray filters, lamp filaments, spot welding electrodes, rayon spinnerets, electrical condensers, electronic tubes, flash light bulbs, for toughing rubber, gas, mantles, etc. The only important zirconium mineral is

Silicate .. .. Zircon, $ZrSiO_4$.

ZIRCON

COMP. $ZrSiO_4$. Zirconium silicate. CRYST. SYST. Tetragonal. COM. FORM. Prismatic Crystals and also in detrital rounded grains. COLOUR. Colourless, reddish brown, grey, pale yellow, greenish. STREAK. Colourless. CLEAV. Indistinct. LUSTRE. Adamantine. FRACT. Conchoidal. H. 7·5. SP. GR. 4·7. OCCURRENCE. Usually occurs as primary constituents of igneous rocks, also occurs in sedimentary rocks and metamorphic rocks. It occurs as beach sands associated with ilmenite, rutile and monazite.

CERIUM

Cerium (Ce) is the only important rare earth metals and is obtained from Monazite. Cerium metal is produced by the electrolysis of the fused chloride, it is iron-grey in colour and has a metallic lustre. It is used in the form of alloy with other minerals, in the lamps used in hospital and cinemas and for chemical uses. The only important cerium minerals is :

Phosphate .. .. .. Monazite, (Ce, La, Yt) PO_4. with ThO_2 or $ThSiO_4$.

MONAZITE

COMP. (Ce, La, Yt.) PO_4. Phosphate of cerium metals with Lanthanum, Yttrium and with thoria, ThO_2 and SiO_2. CRYST. SYST. Monoclinic. COM. FORM. in crystals, massive and as grains. COLOUR. Pale-yellow to dark reddish brown. STREAK. white. CLEAV. Usually imperfect, basal. LUSTRE. Resinous. FRACT. Conchoidal or uneven. H. 5·5. SP. GR. 5·3. OCCURRENCE. Monazite occurs as an accessory mineral in igneous rocks and also found as a heavy mineral in sedimentary rocks. In India, monazite is found in Travancore, Kerala as beach sand with ilmenite, rutile, zircon, etc.

THORIUM MINERALS

Thorium is a black coloured metal related to titanium and usually associated with cerium. It is a radio-active element. The commercially important mineral of thorium is Monazite. It is a phosphate of cerium metals and it is industrially important for its thorium content. It contains small percentage of thorium oxide and thorium silicate.

It is used in the atomic industry in X-Ray apparatus in the manufacture of gas mantles, in photoelectric and in medicine.

Thorium minerals occur in igneous rocks such as pegmatite, granite, etc. It is found as residue in sediments. In India, monazite, a thorium mineral, is found as beach sands with rutile, ilmenite, zircon, etc. The important thorium minerals are:

Phosphate	Monazite, (Ce. La, Yt) PO_4 with ThO_2 or $ThSiO_4$.
Silicate	Thorite, $ThSiO_4$.
Oxide	Thorianite, ThO_2. U_3O_8.

THORITE

COMP. $ThSiO_4$. Thorium silicate. CRYST. SYST. Tetragonal. COM. FORM. Prismatic Crystals and also in detrital rounded grains. COLOUR. Black; orange-yellow. STREAK. Dark brown. CLEAV. Perfect. LUSTRE. Vitreous. FRACT. Conchoidal. H. 4·5. SP. GR. 5·3. OCCURRENCE. Usually occurs in acid igneous rocks.

THORIANITE

COMP. ThO_2. U_3O_8. Oxide of thorium and uranium. CRYST. SYST. Isometric. COM. FORM. Cube. COLOUR. Black. STREAK. Black. CLEAV. Perfect. LUSTRE. Vitreous. FRACT. Conchoidal. H. 6–5. SP. GR. 9·3. OCCURRENCE. Usually occurs as alluvial deposits associated with orthite, zircon, etc.

CARBON MINERALS

Carbon (c) minerals are found in three different forms, namely transparent and crystallised mineral as diamond, scaly or flake and crystalline as graphite and amorphous as lamp-black, charcoal, soot, etc. These three different carbon forms are chemically identical, but

ary in hardness, specific gravity and other physical properties. The mportant carbon compound are:

Native Carbon	Diamond, C Graphite, C
Hydro Carbon	Bitumen, CnH_2n Petroleum, Hydrocarbon
Amorphous Carbon	Coal, C, O, H.
Carbonates	Magnesite, $CaCO_3$, $MgCO_3$, Siderite, $FeCO_3$.

DIAMOND

COMP. C. Pure Carbon. CRYST. SYST. Isometric. COM. FORM. Octahedral, hexoctahedral and other forms, Massive, crystals often twinned and distorted. COLOUR. Usually white or colourless, sometimes with pale shades of yellow, orange. blue, green, red, brown and black. STREAK. Uncoloured. CLEAV. Highly perfect. LUSTRE. Brilliantly adamantine to greasy. FRACT Conchoidal, brittle. H. 10. SP. GR. 3·51–3·52. VARIETIES. *Ordinary* colourless rounded faces crystals *Bort* or *Bortz* and *Carbonado* are black varieties diamond. OCCURRENCE. Occurs in basic and ultra-basic igneous rocks and in alluvial deposits. USES Used as gems and abrasives.

GRAPHITE, Plumbago, Black Lead

COMP. C. Pure Carbon. CRYST. SYST. Hexagonal. COM, FORM. Rhombohedral, crystals rare, occurs in scales, lamenae or columnar masses, granular, earthy and compact. COLOUR Iron black to steel grey. STREAK. Black and shinning; CLEAV. Basal, perfect. LUSTRE. Metallic, dull, earthy. FRACT. Uneven. H. 1–2. SP. GR. 2–2·3. SP. PROP. Thin laminae, flexible, good conductor of heat and electricity. Graphite is distinguished from molybdenite by its jet black streak, the streak of molybdenite is greenish black.

COAL

COMP. Composed of various proportions of carbon, oxygen, hydrogen with small amounts of nitrogen and sulphur. CRYST. SYST. Without crystalline structure. COM. FORM. Compact; massive, laminated. COLOUR. Greyish black to Jet black. STREAK. Greyish black to black. CLEAV. Absent, breaks with more or less

smooth surface along certain direction. LUSTRE.* Brilliant shinning, glossy, dull. FRACT. Conchoidal to uneven, brittle. H. 0·5–2·5. SP. GR. 1–1·80. VARIETIES. Coals are divided into four varieties based on the nature and composition of the organic matter of a coal, its volatile matter yields calorific value and moisture. The four main types of coal are Anthracite, Bituminous, Lignite and Peat. Cannel Coals and Anthracite Coals are in India.

Anthracite : Anthracite is a black and hard coal. Its streak is black and it does not soil finger. It has a brilliant lustre and breaks with a conchoidal fracture. It is difficult to ignite readily and burns with a short, faint blue flame without smoke. Fuel ratio is mostly over 10, Hardness is 2·75 to 3 and specific gravity is 1·27 to 1·70; Calorific value, 14500 to 15000 B. T. U.; Carbon 93—95 per cent; Volatile matter, 3—5 per cent. True anthracite does not occur in India and semi-anthracite is rare.

Bituminous Coal : Bituminous coals are brittle, dense, dark in colour; banded and well jointed coals. They usually break into prismatic and cubical blocks. This coal does not disintegrate when exposed to air. They burn with a yellow smoky flame. The coals yield from 15 to 45 per cent; Volatile matter; Carbon, 85 to 96 per cent; Calorific value, 14000—16000 B. T. U.; the hydrogen 4—5; Oxyegn 2—7 per cent. Fuel Ratio is 1·2—7. This type of coal may be *coking* or *non-coking*. The bituminous coal or humic coal, including domestic coal, coking coal, steam coal consists of a stratified, compressed and altered mass of all kinds of vegetable matter in various stages of formation. It is well jointed, laminated, breaking into rectangular lump. Usually they are used in the manufactrure of metallurgical coke. In India, the Lower Gondwana coals are of this type.

Caking or Coking Coal : A bituminous coal which softens and becomes pasty in the fire. This softening of coal takes place at the temperature of decomposition with the escape of bubbles of gas. On increasing the heat, the volatile products of the soften mass are driven off and the coke is left. Amount of coke left varies from 50—85 per cent.

Non-Caking Coal : Bituminous coal which burns freely without softening or fusion.

Cannel Coal : Cannel coal is compact and black coloured and is often caking. It has no lustre. It breaks with conchoidal fracture. It ignites easily and burns with a steady luminous flame. The term cannel coal is now-a-days mainly used for sapropelic coal containing spores in contrast to sapropelic coal containing algae which is called boghead coal. Macroscopically it is not possible to distinguish

between the boghead coal and the cannel coal but the distinction can be made microscopically excepting in high rank coals. Under the microscope cannel coal shows varying composition considerably. The macerals are intimately mixed and finner. Macroscopically cannel coal often shows microstratification. Cannel coals are found to occur in layers or lenses upto several centimetres in thickness. They have wide occurrence but are in limited amounts. It yields 30—40 per cent volatile matter. Calorific value is 12000—16000 B. T.U. and the carbon content is 85—96 per cent.

Lignite : Lignite is the next stage in the formation of bituminous coal from peat. It is brown in colour and contains impressions and remains of woody matter and leaves. It is banded and jointed. Lignites contains high moisture which is reduced on exposure to air. In air dried lignite the moisture is abount 20 per cent oxygen, 5 per cent hydrogen, 1 per cent nitrogen, 2 per cent sulphur, 65 to 75 per cent total carbon and calorific value 7000—11000 B. T. U. It is used for distillation, combustion and gasification. In India, Lignite occurs in the cretaceous formations in Assam, in the tertiary rocks of Assam, Jammu and Kashmir, Rajasthan, Tamil Nadu and Kerala.

Macroscopic Units of Coal

Coal is not a homogenous substances, it is composed of a number of bands. The various bands of banded coals are called vitrain clarian, durain and fusain. The term lithotype was proposed by Seyler in 1954 to designate megascopically the four recognisable bands of bituminous coals. The four bands of coal were described by stopes in 1919 as the four visible ingredients in banded bituminous coals. The following macroscopics are distinguished in coals :

(a) *Vitrain :* It is the very bright portion of a coal and usually it occurs as a thin band. It is jet black in colour with a brilliant lustre and breaks with a conchoidal fracture. Vitrain is a perfectly homogenous material and it seems to represent the hardened colloidal carbonaceous jelly resulting from complete decomposition of plant matter.

(b) *Clarain :* It is less bright then vitrain and it occurs in bands of variable thickness. It has bright colour and silky lustre. It does not show conchoidal fracture. It is less friable than fusian. Clarain bands are also intercalated. It is the coal material which is richest in recognisable matter.

(c) *Durain :* It forms the dull bands of a coal and occurs as thick bands. It is hard, greyish black in colour and breaks with irregular surface. It shows lustreless surface.

(d) *Fusain :* It resembles charcoal so it is also called mineral charcoal. It is soft and soils hand. Fusain is black in colour and powdery in nature. It occurs as patches and wedges and shows fibrous structure. It is more friable than clarain.

Formation of Coal

It is universally believed that the vegetal matter is the prime source material for coal formation. Two conditions mainly control the formation of coal, firstly, the environmental condition favouring the growth of abundant vegetation which in turn supplier enough vegetable matter to form thick coal seams and secondly swampy and marshy condition which favoured the bacterial decay and decomposition of plant material.

But the transformation of vegetable matter into coal is brought about in two stages :

(a) Peat forming stage or Bio-chemical stage : This process is called Humification Process.
(b) Geo-chemical stage i.e. conversion of peat into higher ranks of coal. This is called as Coalification Process.

Occurrence : Coal is now regarded as a rock, forming one of the units of the earth's crust. Coal occurs as a sedimentary rock in association with sandstone, carbonaceous shale and occasionally fire clay in a regular succession and with repeatations Igneous intrusions in the forms of dykes and sills are present in the coal seams.

Origin : The coal is originated from plant debris. But there is a strong controversy regarding the mode of accumulation of the plant materials which ultimately gave rise to coal seams. Two quite opposed views have been advanced to explain the origin of coal. One theory called 'growth in situ theory', suggests the origin of coal as derived from plant debris that had accumulated in the place where they originally grew. Whereas according to the second theory called the 'drift theory' the plant materials have been transported by water from the place where they grew and had accumulated in a peat swamp and estuarine lakes and seas, had been converted latter sediment and had undergone changes that give rise to coal seams.

BITUMEN : Bitumens are essentially a complex mixture of hydrocarbon compounds, paraffin series (CnH_2n_{-2}) and napthene series (CnH_2n) with minor amounts of nitrogen, sulphur and oxygen. The bitumens include liquid (Sp. Gr. 0·771) to solid bitumens.

PETROLEUM : Petroleum also called rock oil is a *natural fuel*

or a *mineral fuel* or a fossil fuel. This is one of the essential commodities of modern civilization. The word is derived from the Latin word *petra* means rock and *oleum* means oil. It occurs in the earth as gas, liquid, semi-solid and solid state. Chemically it is a compelx mixture of hydrocarbon compounds with minor amounts of impurities, viz. nitrogen, sulphur and oxygen. It is immiscible with water and floats on it. It is soluble in ether, benzene, naptha and carbon disulphide. Liquid petroleum is called crude oil, petroleum gas is called natural gas and solid and semi-solid petroleum are called gilsonite, asphalt, pitch, albertite and tar.

Naptha : A general name for mixtures of hydrocarbons in various proportions, obtained from paraffin oil, coal tar, etc.

Mineral Oil : A mixture of hydrocarbons obtained in the distillation of petroleum, e.g. kerosene.

Amber : Amber is a fossil resin; it is orange-yellow with brownish, reddish, whitish tints. At 150° begins soften and finally melts at 250°—300°.

Asphalt, Mineral Pitch, Asphaltum : Asphalt, Mineral Pitch, Asphaltum is a mixture of different hydrocarbons and part of which are oxygeneted. It is amorphous and brownish black to black in colour, with black pitch like lustre. It melts between 90°—100° and burns with a bright flame. It occurs in the rocks of no particular age. The deposits are surficial with some kind of bituminous material or vegetable remains.

Elaterite, Elastic Bitumen, Mineral Caoutchoue : Elaterite, Elastic Bitumen, Mineral Caoutchoue are usually dark brown, soft, elastic solid bitumen, much like India-rubber and occassionally hard and brittle.

Albertite, Gilsonite, Grahamite, Uintaite, Wurtzillite : are varieties of solid bitumen and are jet black in colour. They are soluble in oil turpentine, ether, benzene, carbon disulphide, etc. They differ slightly in their chemical and physical properties.

Ozokerite, Hatchettine : Ozokerite is a dark yellow or brownish colour with a greenish opalescence and resembles bee wax in appearance. Hatchettine is a yellowish or colourless, soft beewaxy substance.

Copalite, Highgate Resin, Gum Copal : Copalite or Highgate resin is a pale yellow or brownish colour waxy substance. It is like the resin copal in colour, lustre, hardness, etc. and it is difficult solubility in alcohol. Gum Copal is resin copal found in recent sandy sediments.

SILICON MINERALS

Silicon (Si) does not occur in a free state in nature and but occur as compounds. Silicon minerals occur as rock forming silicates in pegmatites, granites and other rocks. It constitutes about 29 per cent of the earth's crust. The quartz, the oxide of Silicon (SiO_2) is the most important rock-forming minerals. Silicon minerals are non-metals similar to carbon in its chemical properties. They occur in two allotropic forms, a brown, amorphous powder and crystals. It is used in alloys and in the form of silicates, in ceramics, refractories, etc. It occurs in the form of quartz, agate, chalcedony, flint, opal (hydrated silica), etc.

Silicate Group : The large number of silicon minerals known as silicates are classified on the basis of the structural arrangements of their constituent atoms and the structures have been elucidated by the methods of X-ray analysis. The unit of all silicate structures is SiO_4 group of atoms. The silica group of minerals have structures consisting of three-dimensional lattices of SiO_4 tetrahedra, in which all four oxygens of each tetrahedron are shared by adjoining tetrahedra. The structures are as follows:

(i) *Separate SiO_4-tetrahedra :* occur in minerals such as olivine (Mg_2SiO_4) and garnet,

(ii) *Si_2O_7 groups of two linked tetrahedra :* occur in minerals such as melilite, $Ca_2MgSi_2O_7$.

(iii) *Ring structures :* found in the mineral beryl, $Be_3Al_2(Si_6O_{18})$.

(iv) *Single chain structures :* found in the pyroxene group of minerals, e.g. diopside, $CaMg(Si_2O_6)$.

(v) *Double chain structures :* found in the Amphibole group of minerals, e.g. tremolite, $Ca_2Mg_5(Si_4O_{11})_2(OH)_2$ and hornblende.

(vi) *Sheet Structures :* found in flaky minerals such as the micas, chlorites, talc, the clay minerals, etc. e.g. Muscovite, $KAl_2(AlSi_3)O_{10}(OH)_2$.

(vii) *Framework structures :* found in orthoclase $K(AlSi_3)O_8$.

The common rock forming silicates :

(i) *Amphibole family* :	(Si_4O_{11}) group	Hornblende, tremolite, actinolite.
(ii) Chlorite family :	(Si_4O_{11}) group :	Chlorite.
(iii) Feldspar family :	(SiO_2) group :	Orthoclase, Plagioclase, Microcline, etc.
(iv) Feldspathoid family :	(SiO_2) group	Leucite, Nepheline, Sodalite, etc.

(v) Mica family:	$(Si_4 O_{10})$ group:	Muscovite, biotite, etc.
(vi) Olivine family:	$(Si O_4)$ group:	Olivine, forsterite, fayalite.
(vii) Pyroxene family:	$(Si_2 O_6)$ group:	enstatite, hypersthene, diopside, augite, etc.
(viii) Quartz:	$(Si O_2)$ group:	Quartz, Chalcedony, etc.

The other important rock forming silicate minerals are: Garnet family; Epidote family—Zoisite, Epidote, Orthite; Sphene; Topaz; Aluminium; Silicate family—Andalusite; Sillimanite, Kyanite; Staurolite; Melilite; Idocrase; Tourmaline; Cordierite; Chloritoid family—Chlorite; Hydrous magnesium silicates—Talc; Serpentine; Hydrous aluminium silicates—Kaolinite; Zeolite family—Analcite; Natrolite, etc. Scapolite family—Scapolite; Axinite; Wollastonite; Glauconite.

The metallic silicates are Beryl, Spodumene, Zircon.

AMPHIBOLE GROUP

The amphibole group of minerals are important rock forming minerals which include minerals whose chemical and physical characters serve to link them together in one family. Amphiboles are silicates of aluminium, iron, magnesium, sodium, potassium and calcium. The atomic structure (double chain structures) of the amphiboles has been investigated by X-ray analysis. The amphiboles minerals crystallise in the orthorhombic, monoclinic and triclinic systems. The prismatic angle of the crystals of the amphibole minerals are nearly 124° and possess good cleavage parallel to the prism (110). The Amphibole minerals may be divided into groups as shown below:

I. *Orthorhombic Amphibole*

Anthophyllite,	$(Mg, Fe) SiO_3$

II. *Monoclinic Amphibole*

Cummingtonite,	$(Mg, Fe) SiO_3$
Grunerite,	$(Fe, Mg) SiO_3$
Tremolite,	$CaMg_3 (SiO_3)_4$
Actinolite,	$Ca (Mg, Fe)_3 (SiO_3)_4$

Hornblende,	$Ca(Mg, Fe)_3 Si_4 O_{12}$
Glaucophane,	$Na(Al, Fe) (SiO_3)_2$ with (Mg, Fe)
Arfvedsonite,	$Na_3 Mg_4 AlSi_8 O_{22} (OH)_2$
Hastingsite,	$Ca_2 Na (Fe, Mg)_4 (Al. Fe) (OH)_2 (Al, Si)_8 O_{22}$
Riebeckite,	$Na Fe (SiO_3)_2$ with $FeSiO_3$
III. *Triclinic Amphibole*	
Cossyrite,	$(Fe Na_2) (Si, Ti) O_3 Na (Al, Fe) (SiO_3)_2$

ANTHOPHYLLITE

COMP. $(Mg, Fe) SiO_3$. Magnesium iron silicate. CRYST. SYST. Orthorhombic. COM. FORM. Usually fibrous, massive lameller. Crystals rare, prismatic habit. COLOUR. Brownish, yellowish brown, brownish green. STREAK. Uncoloured or greyish. CLEAV. Perfect, parallel to prism (110). LUSTRE. Transparent to sub-stranslucent, Vitreous. FRACT. Uneven. H. 5·5–6; SP. GR. 2·8–3·23. VARIETY : Amosite a long fibre anthophyllite. OCCURRENCE. Occurs as a constituent mineral of some metamorphic rock such as anthophyllite, schists and gneisses.

HORNBLENDE

COMP. $Ca (Mg, Fe)_3 Si_4 O_{12}$. Silicate of calcium, magnesium, iron with sodium, potassium, alumium. CRYST. SYST. Monoclinic. COM. FORM. Occurs as prismatic crystals and also as massive, granular, fibrous, etc. COLOUR. Greenish black or black. STREAK. Uncoloured. CLEAV. Perfect two sets, parallel to the prism (110). LUSTRE. Vitreous to pearly. FRACT. Subconchoidal, uneven, brittle. H. 5–6. SP. GR. 2·9–3·4. VARIETY: *Edinite*, light coloured hornblende, *Pargasite*, dark-green or bluish green hornblende. Basaltic Hornblende, a brown or dark coloured hornblende. OCCURRENCE.. Occurs as a primary mineral in igneous rocks such as granites, syenite, diorite, etc. and in metamorphic rocks, such as amphibolites, hornblende schists and gneisses.

TREMOLITE

COMP. $CaMg_3 (SiO_3)_4$. Calcium-magnesium amphibole. CRYST. SYST. Monoclinic. COM. FORM. Crystals long bladed, columnar, fibrous radiating, massive granular. COLOUR. White to grey. STREAK. Uncoloured. CLEAV. Perfect, parallel to the prism (110). LUSTRE. Vitreous. FRACT. Uneven, H. 5–6. SP. GR. 2·9–3·2. OCCURRENCE. Occurs in crystalline limestones, calc-silicate hornfelses, greenstones and serpentines.

ACTINOLITE

COMP. Ca (Mg, Fe) $_3$ $(SiO_3)_4$. Calcium-magnesium-iron amphibole. CRST. SYST. Monoclinic. COM. FORM. Crystals short or long bladed prisms, massive, granular, fibrous, radiating. COLOUR. Bright green and greyish green. STREAK. Uncoloured. CLEAV. Perfect, parallel to the prism (110). LUSTRE. Vitreous. FRACT. Even. H. 5–6. SP. GR. 3–3·2. VARIETY: Uralite, the actinolite amphibole. OCCURRENCE. Occurs in metamorphic rocks such as actinolite schists and greenstones.

CUMMINGTONITE

COMP. (Mg, Fe) SiO_3. Magnesium iron silicate. CRYST. SYST. Monoclinic COM. FORM. Fibrous, radiated or lameller. COLOUR. Brown. STREAK. Uncoloured. CLEAV. Perfect; Prismatic. LUSTRE. Silky. FRACT. Even. H. 5–6. SP. GR. 3·1–3·5. These values increase with increasing percentage of iron. OCCURRENCE. Occurs as constituent minerals in metamorphic rocks.

GRUNERITE

COMP. (Fe, Mg) SiO_3. Iron magnesium silicate. CRYST. SYST. Monoclinic. COM. FORM. Usually lameller or fibrous. COLOUR. Brown. STREAK. Uncoloured. CLEAV. Perfect, prismatic. LUSTRE. Silky. FRACT. Uneven. H. 5–6. SP. GR. 3·4–3·6. OCCURRENCE. Occurs in metamorphic rock.

GLAUCOPHANE

COMP. Na (Al, Fe) (SiO_3) with (Mg, Fe) SiO_3. Silicate of sodium, magnesium, iron and aluminium, CRYST. SYST. Monoclinic. COM. FORM. Crystals prismatic, commonly fibrous, massive, granular or columnar. COLOUR. Blue, bluish black, greyish. STREAK. Greyish blue. CLEAV. Perfect. LUSTRE. Vitreous or pearly. FRACT. Conchoidal or Uneven. H. 6–6·5. SP. GR. 3–3·15. OCCURRENCE. Occurs in metamorphic rock.

RIEBECKIT..

COMP. Na Fe $(SiO_3)_2$ with Fe SiO_3 Sodium iron silicate. CRYST. SYST. Monoclinic. COM. FORM. Prismatic crystals, radiated or longitudinally striated. COLOUR. Dark blue or black. STREAK. Bluish grey. CLEAV. Perfect, prismatic. LUSTRE. Vitreous. FRACT. Sub-conchoidal. H. 4. SP. GR. 3·4. VARIETIES. *Crocidolite,* indigo-blue colour fibrous structure, amphibole, *Cat's*

Eye used for ornaments. *Crosite,* a soda-rich amphibole. OCCURRENCE. Occurs as a constituent mineral in acid igneous rocks.

ARFVEDSONITE

COMP. $Na_3\,Mg_4\,Al\,Si_8\,O_{22}\,(OH)_2$. Sodium magnesium aluminium silicate. CRYST. SYST. Monoclinic. COM. FORM. Prismatic crystals, usually in aggregates. COLOUR. Pure black. STREAK. Deep bluish grey. CLEAV. Perfect prismatic. LUSTRE. Vitreous, FRACT. Subconchoidal. H. 6. SP. GR. 3·44. OCCURRENCE. Occurs as constituents of igneous rocks such as soda-granites, nephelene syenites, pegmatites, etc.

COSSYRITE

COMP. $(FeNa_2)\,(Si,Ti)\,O_3$. $Na\,(Al,Fe)\,(SiO_3)_2$. Titano-silicate of ferrous iron, sodium, aluminium and ferric iron. CRYST. SYST. Triclinic. COM. FORM. Prismatic crystals. COLOUR. Black. STREAK. Greyish black. CLEAV. Perfect, prismatic. LUSTRE. Vitreous. FRACT. Subconchoidal. H. 5–6. SP. GR. 3·7–3·8. OCCURRENCE. Occurs in soda rich igneous rocks.

ASBESTOS : Asbestos (fibrous forms of amphibole) are white to brownish in colour, with long, fine flexible fibre which can be easily separated by fingers. The commercial asbestos are

(i) Crocidolite,	fibrous soda-amphibole
(ii) Actinolite,	asbestos proper
(iii) Chrysotite,	fibrous serpentine
(iv) Amosite.	fibrous anthophyllite

MICA GROUP

Mica is an important group of rock-forming minerals. It is essential to the electrical industries for insulation because of some of its physical properties and crystal form. As there is no other substitute for many of its properties specified for electrical industry, it is commercially workable.

As a consequence of sheet structure all micas possess of an important property —a perfect basal eleavage which permits it to be split up into sheets of films sometimes up to 1/1000 of an inch thickness. This property together with low heat conductivity, flexibility, toughness and high dielectric strength make the light coloured micas electrical insulators. Muscovite can resist temperature up to 550°C and phlogopite upto 1000°C.

Muscovite and biotite are commercially used. Vermiculite is employed for sound and heat installation. Lithium and Vanadium micas are the sources of those elements.

Sheet micas are largely used for electrical insulation in condensers, radios, tubes, while larger ones are used in electrical heaters and smaller ones in discs, washers etc for electric light sockets and fuses. Sheets are also used for heat, windows and gas musks.

Ground mica is generally employed as a filler, lubricant, absorbent, dusting powder, packing material. It is also used in wall paper, roofing, paper paints.

Mica minerals have wide occurrences in igneous sedimentary and metamorphic rocks found under different geological conditions. They occur in schists, granites, marbles, soils, veins, pegmatites lavas and also as weathering products of other minerals. Mica occurs in silicic pegmatites in association with granitic intrusives. The pegmatite rocks, in which mica occurs, traverse through the schistose and gneissose rocks as veins. The largest book of mica found is about 14 feet diameter and 33 feet in length. The main mica minerals are :

Mineral	*Commercial Name*	*Chief constituents in addition to Al & SiO_2*
Muscovite	White mica	Potash
Biotite	Black mica	Magnesia, Potash, Iron
Phlogopite	Amber mica	Magnesia, Potash
Lepidolite	Lithia mica	Lithium, fluorine, Potash (described under Lithium)
Zinnwaldite	Lithia iron mica	Lithium, Iron (described under Lithium) Potash, fluorine
Paragonite	Sodium mica	Sodium, Aluminium, hydroxyl
Vermiculite	Jeffersite	Magnesium, Iron, Potash.
Roscoelite	Vanadium mica	Vanadium, Magnesium, Iron
Fuchsite .	Chrome mica	Chrome

MUSCOVITE, Potash Mica

COMP. KAl_2 $(AlSi_3)O_{10}$ $(OH, F)_2$. Orthosilicate of aluminium and potassium, with hydroxyl and fluorine. CRYST. SYST. Monoclinic. COM. FORM. Tabular crystals, platy, scaly massive, foliated. COLOUR. White, grey, brown, yellowish. STREAK. Uncoloured. CLEAV. Perfect basal. LUSTRE. Pearly, transparent to translucent. H. 2–2·5. SP. GR. 2·7–3·00. OCCURRENCE. Occurs as a constituent of acid igneous rocks, such as granite, pegmatite, sedimentary rocks and metamorphic rocks. USE. Used in the electric industry, wallpaper, paint industry, etc.

LEPIDOLITE, Lithia Mica

COMP. $(OH, F)_2$ KLi_2Al (Si_4O_{10}). Silicate of aluminium, potassium and lithium with hydroxyl and fluorine. CRYST. SYST. Monoclinic. COM. FORM. Tabular platy crystals, massive with small scales or granules. COLOUR. Rose-red, violet grey, (liac) yellowish, white. STREAK. White or uncoloured. CLEAV. Perfect, basal, LUSTRE. Pearly. FRACT. Even. H. 2·5–4. SP. GR. 2,8–3,3, OCCURRENCE. Occurs in pegmatites, associated with tourmaline, topaz, etc.

BIOTITE

COMP. $(OH, F)_2$ $K(Mg, Fe)_3$ $(AlSi_3)O_{10}$. Silicate of magnesium, iron, aluminium and potasium with hydroxyl and fluorine. CRYST. SYST. Monoclinic, pseudorhombohedral. COM. FORM. Tabular and prismatic crystals. COLOUR. Usually black to dark green. STREAK. Uncoloured. CLEAV. Perfect, basal. LUSTRE. Splendent, pearly on the cleavage surface. FRACT. Even. H. 2·5–3 SP. GR. 2·7–3·1. VARIETY. *Lepidomelane* and *Haughtonite* are iron rich biotite. OCCURRENCE. Occurs as an original constituent of igneous rocks such as granites, diorites, gabbros and in metamorphic rocks.

PHLOGOPITE

COMP. $(OH, F)_2$ $KMg_3(AlSi_3)O_{10}$. Silicate of aluminium, magnesium and potassium with hydroxyl and fluorine. CRYST. SYST. Monoclinic. COM. FORM, Prismatic crystals and in scales. COLOUR. Yellowish, brown, white, green, colourless, reddish. CLEAV. Perfect, basal. FRACT. Even. H, 2·5–3. SP. GR. 2·78–2·85. OCCURRENCE. Occurs in crystalline limestones and also igneous rocks.

ZINNWALDITE

COMP. Silicate of magnesium iron, aluminium and potassium with hydroxyl, fluorine and lithium. COLOUR. Pale violet, yellow, dark grey to brown. Other characters same as lepidolite. Zinnwaldite occurs in granites and pegmatites containing topaz and cassiterite.

PARAGONITE

COMP. Sodium mica. $(OH)_2\ NaAl_2(AlSi_3)O_{10}$. Silicate of sodium and aluminium with hydroxyl. COLOUR. Yellowish or greenish, other properties like muscovite. Paragonite occurs in metamorphic rocks associated with kyanite, staurolite and garnet.

CLINTONITE GROUP

The Clintonite mineral group are sometimes called Brittle Micas. They form a transition from the mica proper to chlorite. Their properties are same as Mica. The clintonite minerals are :

1. MARGARITE–calcium mica, basic silicate of aluminium and calcium.
2. CHLORITOID–basic silicate of aluminium and ferrous iron with magnesium.
3. SEYBERTITE–basic silicate of calcium, magnesium with aluminium.

CHLORITE GROUP

The chlorite group takes its name from the mineral chlolorite. This group of minerals have the Si_4O_{10}-sheet structure. They are hydrous silicates of aluminium, iron and magnesium. The varieties of chlorite group of minerals are Clinochlore, Penninite, Vermiculite and Repidolite. They are related to the Micas in composition but they do not contain alkalies.

CHLORITE

COMP. $(OH)_8\ Al(AlSi_3)O_{10}\ (Mg,Fe)_5$. Hydrous silicate of aluminium, iron and magnesium. CRYST. SYST. Monoclinic COM. FORM. Usually granular masses, foliated, in scales, and also in tabular crystals. COLOUR. Green. STREAK. Greenish white, CLEAV. Perfect, basal. LUSTRE. Pearly, FRACT. Uneven. H. 1·5–2·5, scratched by finger nail. SP. GR. 2·65–2·94. SP. PROP. Slightly greasy. OCCURRENCE. Occurs in igneous, sedimentary and metamorphic rocks.

FELDSPAR GROUP

The feldspar form an important group of the rock forming minerals. They are found as main constituents of most crystalline rocks. Feldspars are aluminous silicate of sodium, potassium, barium or calcium. The silicate structure of the feldspars is of the three dimensional framework type. They are used as gemstones, in ceramic industry, roofing materials, abrasives, etc. In India, feldspar are found in the mica bearing pegmatites of Ajmer, Mewar and Alwar, in Rajasthan, in granites and pegmatites of Burdwan and Bankura in West Bengal, Bihar, Orissa, Andhra Pradesh, Gujarat. The important minerals are :

Monoclinic Feldspar

Orthoclase	$KAlSi_3O_8$,	potassium aluminium silicate
Hyalophane	$(K_2Ba)\ Al_2Si_4O_{12}$,	potassium, barium aluminium silicate
Celsian	$BaAl_2Si_2O_8$	Barium Aluminium silicate

Triclinic Feldspar

Microcline	$KAlSi_3O_8$,	potassium aluminium silicate
Anorthoclase	$(Na, K)\ AlSi_3O_8$,	sodium, potassium, aluminium silicate

Plagioclase Feldspar (Albite-anorthite series)

Albite,	$Na\ AlSi_3O_8$,	sodium aluminium silicate
Oligoclase, Andesine, Labradorite, Bytownite,	$n\ Na\ AlSi_3O_8$ $m\ Ca\ Al_2Si_2O_8$	sodium calcium aluminium silicate
Anorthite	$Ca\ Al_2Si_2O_8$	calcium aluminium silicate

ORTHOCLASE

COMP. $KAlSi_3O_8$. Potassium aluminium silicate. CRYST. SYST. Monoclinic. COM. FORM. Usually in prismatic crystals, also occur as massive. COLOUR. Flesh-coloured, reddish white, white, colourless, etc. STREAK. Uncoloured. CLEAV. Perfect, basal 2 sets. LUSTRE. Vitreous to pearly. FRACT. Conchoidal or uneven. H. 6. SP. GR. 2·58. OCCURRENCE. Occurs as essential minerals in igneous rocks such as pegmatites, granites, etc. VARIETY. Soda-orthoclase is a variety of orthoclase and is a link between orthoclase and albite.

HYALOPHANE

COMP. $(K_2Ba)\,Al_2Si_4O_{12}$. Potassium barium aluminium silicate. CRYST. SYST.. Monoclinic. COM. FORM, Crystals adularia, also massive. COLOUR. White, flesh coloured. STREAK. Uncoloured. CLEAV. Perfect, prismatic. LUSTRE. Vitreous. FRACT. Conchoidal. H. 6-6·5. SP, GR. 2·8. OCCURRENCE. Occurs in a granular dolomite along with barite. It is a rare mineral.

CELSIAN

COMP. $Ba\,Al_2Si_2O_8$. Barium aluminium silicate. CRYST. SYST. Monoclinic. COM. FORM. Usually massive, in crystals also. COLOUR. Usually colourless. STREAK. Colourless. CLEAV. Perfect 2 sets. LUSTRE. Vitreous. FRACT. Even. H. 6-6·5, SP. GR. 3·37. OCCURRENCE. Occurs in dolomitic Limestone. It is not a common feldspar.

MICROCLINE

COMP. $KAlSi_3O_8$. Potassium aluminium silicate. CRYST. SYST. Triclinic. COM. FORM. Usually in crystals also massive or granular. COLOUR. Greenish white, greyish white, pinkish. STREAK. Uncoloured. CLEAV. Perfect 2 sets. LUSTRE. Vitreous. FRACT. Even, H. 6-6·5. SP. GR. 2·56. OCCURRENCE. Occurs in acid igneous rocks such as pegmatites, granites. VARIETY. Anorthoclase Soda-microcline is a variety of microcline and is an alkali feldspar in which Na with K in excess, the formula is $(Na, K)\,AlSi_3O_8$.

PLAGIOCLASE

COMP. $(n\ Na\,AlSi_3O_8)$. $(m\ Ca\,Al_2Si_2O_8)$. Sodium calcium aluminium silicate. The following members of the plagioclase series are as follows:

Ab stands for Albite and An stands for Anorthite.
Albite–Ab_{100} An_0 to Ab_{90} An_{10} (with less than 10% An).
Oligoclase–Ab_{90} An_{10} to Ab_{70} An_{30} (with less than 10-30% An).
Andesine–Ab_{70} An_{30} to Ab_{50} An_{50} (with 30-50%)
Labradorite–Ab_{50} An_{50} to Ab_{30} An_{70} (with 50-70% An)
Bytonite–Ab_{30} An_{70} to Ab_{10} An_{90} (with 70-90% An)
Anorthite–Ab_{10} An_{90} to Ab_0 An_{100} (with more than 90% An)

CRYST. SYST. Triclinic. COM. FORM. Perfect, two sets. COLOUR. white, greyish white. STREAK. Uncoloured. CLEAV. Perfect, 2 sets. LUSTRE. Vitreous. FRACT. Conchoidal. H, 6. SP. GR. Albite 2·6-2·62; Oligoclase 2·64; Andesine 2·66. Labradorite 2·67; Bytonite. 2·72; Anorthite 2·74. OCCURRENCE. Occurs as a primary constituent of acid basic and ultrabasic igneous rocks such as granites, pegmatites, gabbro, norite dolerite and basalt.

Perthite : Perthite consists of interlaminated of albite and orthoclase or microcline. *Microperthite* is a finer interlaminated recognisable only under microscope and crytoperthite structure is so finer structure which cannot be recognisable under microscope.

FELSPATHOID GROUP

The Feldspathoid group consists of certain minerals which show simitarities with the feldspar group, especially in their chemical composition. The important feldspathoid family:

Leucite, $KAlSi_2O_6$
Nepheline, $NaAlSiO_4$
Sodalite, $3(NaAlSiO_4)$. NaCl
Lazurite, $3(NaAlSiO_4)$ Na_2S
Cancrinite, $4(NaAlSiO_4)$ $CaCo_3$. H_2O
Hauyne, $3(NaAlSiO_4)$. $CaSO_4$
Nosean, $3(NaAlSiO_4)$. Na_2SO_4

LEUCITE

COMP. $KAlSi_2O_6$. Potasium aluminium silicate. CRYST. SYST. Isometric. COM. FORM. Usually in crystals, rarely massive, granular COLOUR. White, ash gray or smoke gray. STREAK. Uncoloured. CLEAV. Very imperfect. LUSTRE. Vitreous. FRACT. Conchoidal, brittle. H., 5·5–6. SP. GR. 2·5. OCCURRENCE. Occurs as a primary constituent of volcanic rocks. USE. Used for the production of potash feldspar and of aluminium.

NEPHELINE, NEPHELITE

COMP. $NaAlSiO_4$. Sodium aluminium silicate. CRYST. SYST. Hexagonal. COM. FORM. Usually in prismatic crystals, also in massive. COLOUR. White or colourless, brownish, yellowish, dark grey, bluish grey, etc. STREAK. Uncoloured. CLEAV. In perfect prismatic basal or indistinct. FRACT. Subconchoidal, brittle. H. 5·5–6. SP. GR. 2·5–2·6. VARIETY. *Eleolite*, is a dark coloured nepheline. OCCURRENCE. Occurs in plutonic igneous rocks, such as Syenites, Nepheline syenites, etc. and in Volcanic rocks such as phonolites, nepheline-basalts, etc.

SODALITE

COMP. $3(Na\,AlSiO_4) . NaCl$. Sodium aluminium silicate with sodium chloride. CRYST. SYST. Isometric. COM. FORM. Usually in crystals rhombododecahedral, also massive. COLOUR. Bluish white, grey, blue, lavender blue, yellowish. STREAK. Colourless. CLEAV. Perfect or indistinct. LUSTRE. Vitreous. FRACT. Conchoidal or uneven brittle. H. 5·5–6. SP. GR. 2·2–2·3. OCCURRENCE. Occurs in soda rich igneous rock such as nepheline-syenite, etc., usually occur with nepheline, leucite, etc.

LAZURITE, Lapis Lazuli

COMP. $3\ Na\,AlSiO_4.\ Na_2S$. Sodium aluminium silicate with sodium sulphide. CRYST. SYST. Isometric. COM. FORM. Usually massive, compact; crystals rare. COLOUR. Azure blue or Berlin-blue, violet blue etc. STREAK. Bluish white. CLEAV. Imperfect. LUSTRE. Vitreous. FRACT. Uneven. H. 5–5·5. SP. GR. 2·3–2·4. OCCURRENCE. Occurs in crystalline limestone. USE. Used for ornamental purpose, powdered mineral is used for blue paint ultramarine.

OLIVINE GROUP

The olivine group consists of an isomorphous series of minerals They are orthosilicate of either magnesium or iron. They are found as important constituent minerals of ultrabasic igneous rocks. The important olivine minerals are :

Olivine :	$(Mg, Fe)_2\ SiO_4$;	magnesium iron orthosilicate.
Forsterite :	Mg_2SiO_4 ;	magnesium orthosilicate
Fayalite :	$Fe_2\ SiO_4$;	iron orthosilicate.

OLIVINE, Chrysolite, Peridot

COMP. $(Mg, Fe)_2 SiO_4$. Magnesium iron orthosilicate. COM. FORM. Prismatic crystals, also massive, granular, compact. COLOUR. Olive green, green, yellowish green. STREAK. Colourless. CLEAV. Imperfect. LUSTRE. Vitreous. FRACT. Conchoidal. H. 6·5–7. SP. GR. 3·27–4·3. VARIETIES. *Forsterite,* yellowish green or white coloured olivine ; *Fayalite,* brownish black coloured olivine ; *Peridot,* gem variety of olivine. OCCURRENCE. Occurs in igneous rocks such as peridotite, dunite, gabbro, dolerite, basalts and also in sedimentary rock such as crystalline limestones.

PYROXENE GROUP

The pyroxene group of minerals are important rock forming minerals whose chemical and physical characters serve to link them together in one family. Pyroxenes are silicates of magnesium, iron, calcium, aluminium, sodium, zinc and lithium and rarely include zirconium and titanium. The atomic structure (double chain structures) of the pyroxene has been investigated by X-ray analysis. The pyroxene minerals crystallises in the orthorhombic, monoclinic and triclinic systems. The prismatic angle of the crystals of the pyroxene minerals are 87° and possess good cleavage parallel to the prism (110). The pyroxene minerals may be divided into groups as shown below :

Orthorhombic Pyroxene

Enstatite,	$MgSiO_3$
Bronzite,	$(Mg, Fe)\ SiO_3$
Hypersthene,	$(Fe, Mg)\ SiO_3$

Monoclinic Pyroxene

Diopside,	$Ca\,Mg\,Si_2\,O_6$
Hedenbergite,	$Ca\,Fe\,Si_2\,O_6$
Augite,	$(Ca, Mg. Fe\,Al)_2\ (Al, Si)_2\,O_6$
Pigeonite,	$(Ca, Mg)\ (Mg, Fe)\ Si_2\,O_6$
Acmite,	$Na\,Fe'''\,(SiO_3)_2$
Jadeite,	$Na\,Al\ (SiO_3)_2$
Spodumene,	$Li\,Al\,Si_2\,O_6$ (described under lithium)
Wollastonite,	$Ca\,Si\,O_3$

Triclinic Pyroxene

Rhodonite, Mn Si O_3

Babingtonite, (Ca, Fe, Ma) Si O_3. Fe_2 $(Si\ O_3)_3$

ENSTATITE

COMP. Mg Si O_3. Magnesium silicate. CRYST. SYST. Orthorhombic. COM. FORM. Usually massive, lameller or fibrous, rarely prismatic crystals. COLOUR. Grey, brown, yellow, green to olive green, colourless. STREAK. Uncoloured or greyish. CLEAV. Perfect in crystals. LUSTRE. Vitreous or pearly. FRACT. Uneven, brittle. H. 5·5. SP. GR. 3·1–3·3. VARIETY. Bronzite, a iron-bearing variety of enstatite. OCCURRENCE. Occurs as primary constituents of the intermediate or basic igneous rocks, such gabbro, diorites and also occurs in peridotites, serpentines.

HYPERSTHENE

COMP. (Fe, Mg) Si O_3 with more than 15 per cent FeO. Iron magnesium silicate. CRYST. SYST. Orthorhombic. COM. FORM, Usually foliated massive, rarely prismatic crystals. COLOUR. Brownish green, greenish black, brown, black. STREAK. Greyish or brownish. CLEAV. Indistinct. LUSTRE. Pearly. FRACT. Uneven, britlle. H. 5–6. SP. GR. 3·4–3·5. OCCURRENCE. Occurs in basic igneous rocks such as gabbro, norite, etc. and in charnockites, hypersthene-hornfels, schists, etc.

DIOPSIDE

COMP. Ca Mg $(Si_2\ O_6)$. Calcium magnesium metasilicate. CRYST. SYST. Monoclinic. COM. FORM. Usually granular, massive, columnar, lamellar, and also in prismatic crystals. COLOUR. White, yellowish, greyish, pale green to dark green. STREAK. Uncoloured. CLEAV. Perfect, 2 sets. LUSTRE. Vitreous. FRACT. Uneven. H. 5–6. SP. GR. 3·2–3·38. OCCURRENCE, Occurs in igneous rocks such as granites, pegmatites, and in metamorphic rocks such as calc-silicate hornfels, crystalline limestone.

AUGITE

COMP. $(Ca, Mg, Fe, Al)_2$ $(Al, Si)_2 O_6$. Silicate of calcium, magnesium, iron and aluminium. CRYST. SYST. Monoclinic. COM. FORM. Crystals common. COLOUR. Black and greenish-black. STREAK. Greyish. LUSTRE. Vitreous. H, 5–6. SP. GR. 3·2–3·5. OCCURRENCE. Occurs in volcanic rocks, basalts, ande-

sites, in basic rocks such as gabbros, dolerite, diorites, etc. and in metamorphic rocks such pyroxenites, peridotites, etc.

ACMITE

COMP. Na Fe (Si_2O_6). Sodium iron silicate. CRYST. SYST. Monoclinic. COM. FORM. In prismatic crystals, also fibrous and accicular crystals. COLOUR. Brown, green. STREAK. Pale brownish grey. CLEAV. Prismatic, perfect. LUSTRE. Vitreous. FRACT. Uneven, brittle. H. 6–6·5. SP. GR. 3·5–3·55. OCCURRENCE. Occurs in igneous rocks, such as phonolites, nepheline-syenites, etc.

JADEITE

COMP. Na Al $(Si\,O_3)_2$. Silicate of sodium and aluminium. CRYST. SYST. Monoclinic. COM. FORM. Usually massive, granular, columnar, fibrous, foliated. COLOUR. Apple green, emerald green, bluish green. STREAK. Greenish white. CLEAV. Prismatic crystals. LUSTRE. Subvitreous, pearly. FRACT. Splintery. H. 6·5–7. SP. GR. 3·3–3·35. OCCURRENCE. Occurs in metamorphic rocks. USE. Used as ornamental stones.

RHODONITE

COMP. Mn $Si\,O_3$. Silicate of Manganese. CRYST. SYST. Triclinic. COM. FORM. Commonly massive, granular, compact, usually in tabular crystals. COLOUR. Brownish red, greenish, yellowish. STREAK. White. CLEAV. Perfect. LUSTRE. Vitreous. FRACT. Conchoidal, uneven. H. 5·5–6·5. SP. GR. 3·4–3·6. OCCURRENCE. Occurs in various manganese ore bodies associated with rhodochrosite.

QUARTZ GROUP

Quartz is a common mineral and some of its varieties are regarded as gems. It is hard, brittle, having conchoidal fracture and no cleavage. It is hexagonal prism or pyramid. *Rock Crystal*, the transparent colourless variety of quartz, is used in Jewellery. *Smoky quartz* are varieties of a smoky brown or smoky yellow colour. *Amethyst* is a purple or violet coloured varieties of quartz. *Citrine* is a light yellow coloured quartz crystal sometimes called *false topaz*. *Milky quartz* is common variety of quartz of milky white colour. Rose quartz is a pale to deep pink or rose coloured variety of quartz. *Cat's eye* is a kind of quartz with a minutely fibrous structure and

when polished it gives a peculiar opalescent play of light. *Tiger's eye* is a fibrous quartz of yellow colour. Quartz which contains spangels of mica, hematite, etc. is called *adventurine quartz*; *ferruginous quartz* is reddish or brownish coloured quartz and contains iron oxide. *Chalcedony* is a fine grained or cryptocrystalline variety of quartz having a waxy lustre and varying in colour from white to grey, blue, brown, red and other shades; *agate* is a variagated chalcedony with the colours arranged in delicate concentric bands frequently alternating with bands of *opal*; *moss agate* is a kind of chalcedony containing brown or black moss like or dendritic forms. *Jasper* is an impure quartz and is usually red in colour from inclusion of hematite : *flint is* compact opaque cryptocrystalline quartz with a dull lustre and is usually grey, black or brown in colour ; *Chert* is a black to grey coloured, opaque cryptocrystalline quartz.

Quartz is used as gem abrasive, building materials, in ceramic industry, as in scouring soaps, sand papers, etc.

Quartz occurs as veins. as an original constituent of acid igneous rocks, as grains in sedimentary rocks and is a common constituent of many metamorphic rocks. The chief producing countries Brazil, Japan, Madagascar, Switzerland and U.S.A. In India, it is found in Madhya Pradesh, Gujarat, Uttar Pradesh, Bihar, Orissa and Rajasthan.

Forms of Silica

Crystalline : Quartz, Tridymite, Cristobalite.
Cryptocrystalline : Chalcedony, Jasper, Flint, etc.
Amorphous Hydrated : Opal, Chalcedony, Sinter, diatomite, etc.

QUARTZ

COMP. SiO_2. Silicon dioxide. CRYST. SYST. Hexagonal. COM. FORM. Usually in hexagonal prismatic crystals; also acicular, massive, granular. COLOUR. White, colourless. STREAK. Uncoloured. CLEAV. Absent. LUSTRE. Vitreous. FRACT. Conchoidal. H. 7 ; cannot be scratched with a knife. SP. GR. 2·65–2·66. OCCURRENCE. Occurs as an main constituent of igneous rocks such as pegmatites, granites, etc. also occurs as veinstone, in sedimentary rocks such as sandstone, in metamorphic rocks such as quartzite. USE. Used as building stones, in ceramic industry, in glass making, as an abrasive as in scouring soaps, tooth paste, sand paper, etc.

CHALCEDONY

COMP. SiO_2. A mixture of crystalline silica and amorphous hydrated silica. COM. FORM. Cryptocrystalline structure, shows radiating, fibrous, mammillary, botryoidal, stalactitic. COLOUR. White, greyish, pale brown, black, etc. STREAK. Uncoloured. CLEAV. Absent. LUSTRE. Waxy. FRACT. Conchoidal or Uneven. H. 6–6·5. SP. GR. 2·59–2·64. VARIETY, Other varieties are *flint,* dull brown or brownish black in colour cryptocrystalline silica; *Jasper,* impure opaque coloured, usually red in colour, cryptocrystalline silica.

OPAL

COMP. $SiO_2 . s H_2O$. Amorphous hydrated silica. COM. FORM, Amorphous, massive, compact, reniform, stalactitic or large tuberose. COLOUR. White, red, brown, grey, yellow, blue, etc. STREAK. White. LUSTRE. Vitreous. FRACT. Conchoidal. H. 5·5–6·5. SP. GR. 1·9–2·3. VARIETY. *Precious opal,* is the gem variety, *Hydrophane,* opaque white or yellowish, variety, *Sinter,* anhydrous silica with loose porous structure, *Diatomite,* is a deposit of tests and skeletons of siliceous organisms. OCCURRENCE. Occurs in filling cracks and cavities in igneous rocks and also embeded in flint like nodules in shales and sandstones.

GARNET GROUP

Garnets are silicates of various metals and garnet is the name given to a group of minerals which have similar crystal habits. It is isometric and is usually in distinct crystals. It is used as gemstone and as abrasives.

Garnet occurs as common accessory minerals of igneous rocks, such as pegmatite, etc. and also occurs in metamorphic rocks. It comes mainly from United States of America, Japan, Czechoslovakia, Srilanka, South Africa and India. In India, garnet is found in Koderma in Bihar, Kishengarh, Jaipur and Mewar in Rajasthan, Nellore in Andhra Pradesh, Tinnevelly and South Kanara in Tamil Nadu, Kerala, Maharastra, Kashmir, Karnataka, Orissa, and several other places in other parts of India.

GARNET

COMP. Ca, Mg, Fe, Mn, Al, Ti, Cn $(SiO_4)_3$. Orthosilicate of Calcium, Magnesium, iron, aluminium, titanium, chromium. CRYST. SYST. Isometric. COM. FORM. Massive, granular, lameller, rarely cubic and octahedral crystals. COLOUR. Red, brown, black,

green, pink. STREAK. White. CLEAV. Perfect. LUSTRE. Vitreous. FRACT. Conchoidal to uneven. H. 6·5–7·5. SP. GR. 3·15–4·3. OCCURRENCE. Occurs as common accessory minerals in igneous, sedimentary and metamorphic rocks. VARIETIES. *Pyrope,* the magnesium garnet, is a deep red coloured garnet and is used as gem. *Almandite,* the almandine garnet, is deep crimson coloured and is used as gem. *Spessarite,* the manganese garnet is orange red in colour and is used as gem. *Grossularite,* the calcium, aluminium, garnet, may be colourless, pale yellow, green, brownish yellow, cinnamon brown and rose red. *Androdite,* the calcium iron garnet, its colour is various shades of green, yellow, brown to black. *Topazolite,* has topaz-yellow colour. *Melanite* is black in colour. *Demantoid* is green in colour and used as gem. *Uvarovite,* the chrome garnet, is a fine emerald green in colour.

EPIDOTE GROUP

The Epidote group minerals of complex orthosilicates of calcium iron, aluminium, manganese, cerium, etc. X-ray studies of epidotes shows all similarities in the their atomic structure and the minerals of epidote group are classified by means of their crystal systems into :

Orthorhombic Epidote

Zoisite,	$Ca_2 Al_3 (SiO_4)_3 (OH)$
Topaz,	$Al_2 F_2 SiO_4$

Monoclinic Epidote

Clinozoisite,	$HCa_2 Al_3 Si_3 O_{13}$
Epidote,	$Ca_2 (Al, Fe)_3 (SiO_4)_3 (OH)$
Piedmontite,	$Ca_2 (Al, Fe, Mn)_3 (SiO_4)_3 (OH)$
Allanite,	$(Ca. Fe)_2 (Al, Fe, Ce)_3 (SiO_4)_3 (OH)$
Sphene,	$Ca Ti SiO_5$

ZOISITE

COMP. $Ca_2 Al_3 (SiO_4)_3 (OH)$. Basic silicate of calcium and aluminium. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic crystals strained longitudinally, usually massive, compact or columnar. COLOUR. Greyish white, greenish, yellowish brown, rose-red. STREAK. Uncoloured. CLEAV. Perfect in crystals.

LUSTRE. Vitreous to pearly. FRACT. Uneven or subconchoidal, brittle. H. 6–6·5. SP. GR. 3·25–3·37. VARIETY, *Thulite,* a rose-red variety of zoisite. OCCURRENCE. Occurs in metamorphic rocks.

EPIDOTE

COMP. $Ca_2(Al, Fe)_3 (SiO_4)_3 (OH)$. Basic silicate of calcium, aluminium and iron. CRYST. SYST. Monoclinic. COM. FORM. Usually prismatic crystals, also fibrous, granular, accicular, deeply striated. COLOUR. Greenish, yellowish green, greenish black, grey, yellow, red, black. STREAK. White. CLEAV. Perfect in crystals. LUSTRE. Vitreous. FRACT. Uneven. H. 6–7, SP. GR. 3·25–3·5. VARIETY. *pistacity*, a green coloured, epidote, *Arendalite*, blackish green, variety, *Withamite,* a red variety of epidote. OCCURRENCE. Occurs usually in metamorphic rocks. sedimentary rock and in certain igneous rocks.

SPHENE, Titanite

COMP. $Ca\,Ti\,SiO_5$. Titanite and silicate of calcium. CRYST. SYST. Monoclinic. COM. FORM. Usually wedge shaped or prismatic in crystals, also massive, granular. COLOUR. Brown, green, grey, yellow, red, black. STREAK. White. CLEAV. Perfect in crystals. LUSTRE. Adamantine to resinous. FRACT. Subconchoidal, brittle. H. 5–5·5. SP. GR. 3·4–3·56. VARIETY, *Titanite,* brown to black coloured sphene, *greenovite,* red or pinkish coloured, *Leucoxene,* alteration product of ilmanite and titaniferous minerals.

The other important minerals of the garnet group are :

Almandine, iron-aluminium garnet, $Fe_3 Al_2 (SiO_4)_3$
Andradite, iron-calcium garnet, $Ca_3 Fe'''_2 (SiO_4)_3$.
Grossularite, calcium aluminium garnet, $Ca_3 Al (SiO_4)_3$.
Pyrope, magnesium-aluminium garnet, $Mg_3 Al_2 (SiO_4)_3$.
Spessartite, manganese-aluminium garnet, $Mn_3 Al_2 (SiO_4)_3$.
Uvarovite, calcium-chromium garnet, $CaCr_2 (SiO_4)_3$.

CHLORITOID (Clintonite) GROUP

The chloritoid minerals resembles the micas some of the physical characters, such as form, cleavage and structure, but they yield laminae brittle. The chief minerals of the chloritoid group are :

Chloritoid .. .. $(Ca, Fe, Mg)\ Al_2\ (Al_2\ Si_2) O_{10} (OH)_2$
(Brittle Micas)

Margarite	.. ..	$H_2 Ca Al_4 Si_2 A_{12}$
Seyberite	.. ..	$H_3 (Mg, Ca)_5 Al_5 Si_2 O_{18}$

CHLORITOID, Oltrelite

COMP. $(Ca, Fe, Mg) Al_2 (Al_2 Si_2) O_{10} (OH)_2$. Silicate of aluminium, calcium, iron and magnesia. CRYST. SYST. Triclinic. COM. FORM. Usually foliated, massive, in laths, brittle. COLOUR. Greenish black, greyish green, dark green. STREAK. Uncoloured or greenish or greyish. CLEAV. Imperfect, laminae brittle. LUSTRE. Pearly on cleavage surface. H. 6·5. SP. GR. 3·53–3·57. OCCURRENCE. Occurs in metamorphic rocks of sedimentary origin.

HYDROUS ALUMINIUM SILICATES, CLAY GROUP

A precise definition of clay is impossible because of its complex composition. But the term may be applied more or less to a natural substance consisting chiefly of alumino silicic acids with colloidal materials and impurities like rock fragments. The clays when wet generally become plastic and can be moulded into desired shapes but become hard (stone like) after firing at a suitable temperature.

The clay minerals occur as very minute lath like, flaky crystals, hollow-tube shaped or fibre like crystals. It is very difficult to identify the clay minerals due to its low double refraction, fineness and the presence of colloidal and amorphous compounds. They have the $Si_4 O_{10}$ sheet structure, are usually recognised by X-Ray. microscope and thermal analysis.

Clays results from the alteration or weathering of aluminous rocks, mainly igneous rocks. In some cases the weathered materials remain where they are formed and give rise to residual clays and in other cases they are transported by various agencies and deposited as beds in lakes, river, seas, etc. The chief clay minerals are :

Kaolinite,	$Al_4 Si_4 O_{10} (OH)_8$
Montmorillonite,	$Al_4 Si_8 O_{20} (OH)_4 . n H_2O$
Pyrophyllite,	$H_2 Al_2 (SiO_3)_4$
Allophanite,	$Al_2 O_3 . SiO_2 . H_2O$

KAOLINITE, China Clay, Kaolin

COMP. $Al_4Si_4O_{10}$ $(OH)_8$. Hydrous aluminium silicate. CRYST. SYST. Triclinic. COM. FORM. Usually clay like mass, soft, compact. COLOUR. White, greyish white, slightly yellowish white, sometimes reddish, brownish or bluish. STREAK. White. CLEAV. Perfect, basal. LUSTRE. Pearly to dull earthy. FRACT. Uneven. H. 2–2·5. SP. GR. 2·6–2·63. SP. PROP. Greasy feel and earthy smell. VARIETIES. *Nacrite, Dickite, Endellite, Anauxite* are crystallised varieties, *Kaoline* or *china clay*, white in colour and dense, *Halloysite*, is amorphous, colloidal, Kaolin like masses, *Lithomarge*, is a yellowish white, reddish coloured, compact variety. OCCURRENCE. Occurs in association with other minerals, results from the alteration or weathering of aluminous rocks, mainly from igneous rocks. USE. Used in the Ceramic industries, in refractory industries, in cement manufacture, for manufacture of switches, insulators, conduits, sockets, wall paper, linoleum, filtering purpose, scouring soaps, etc.

MONTMORILLONITE

COMP. Al_4 Si_8 O_{20} $(OH)_4$. n H_2O. Hydrous aluminium silicate. CRYST. SYST. None, amorphous, orthorhombic. COM. FORM. Massive, clay like. COLOUR. .White, greenish, rose, grey, blue. STREAK. White. CLEAV. Imperfect. LUSTRE. Dull, earthy, feeble. FRACT. Uneven. H. 1–2. SP. GR. 2. SP. PROP, Greasy feel. VARIETIES. *Beidellite,* white or reddish in colour, occurs in thin orthorhombic plates; *Bentonite,* occurs as thin beds, result from the decomposition of volcanic and possess plasticity and swells on wetting. OCCURRENCE. Occurs as an alteration product of aluminium silicates. USE. Used as an absorbent, in medicine, in paper industry, in ceramic industry, etc.

PYROPHYLLITE

COMP. H_2 Al_2 $(SiO_3)_4$. Hydrous aluminium silicate. CRYST. SYST. Orthorhombic. COM. FORM. Foliated, radiated lamellar, fibrous. COLOUR. White, greyish white, brownish green, apple green. STREAK. White. CLEAV. Distinct, basal. LUSTRE. Pearly or dull. FRACT. Uneven. H. 1–2. SP. GR. 2·8–2·9. SP. PROP. Greasy feel, flexible laminae. OCCURRENCE. Occurs as foliated masses in crystalline schists. USE. Used as a filler for paints, paper, rubber, etc. and in plusters.

ALLOPHANITE, Allophane

COMP. Al_2 O_3. SiO_2. H_2O. Hydrous aluminium silicate. CRYST. SYST. None, Amorphous. COM. FORM. In incrustations,

usually with mamillary surface, sometimes reniform. COLOUR. White, pale, sky blue, green, brown, yellow. STREAK. Uncoloured. CLEAV. Imperfect. LUSTRE. Pearly to resinous. FRACT. Conchoidal, brittle. H. 3. SP. GR. 1·85–1·89. OCCURRENCE. Occurs in chalk, sandstone and in lining cavities in clays and marls, found in encrustations on fissures and on joint planes.

FULLER'S EARTH is a type of clay. It is also called bleaching clays. It is bluish, greenish, greyish or yellowish coloured material with earthy texture. It is soft with soapy feel. It is used for filtering purpose and in Ceramic industry.

ZEOLITE GROUP

The Zeolites are hydrated silicates of calcium and aluminium with sodium and potassium. They result from the alteration of the feldspars and alumininous rocks, mainly igneous rocks. They occur as secondary minerals, filling cavities, joint-spaces, cracks and fissures such as basalts, lavas, etc. They have the SiO_4 tetrahedra which are arranged in group of five and are usually recognised by X-Ray and under microscope. The Zeolite minerals are :

Analcite,	$Na\,(Al\ Si_2)\,O_6.\ H_2O.$
Natrolite,	$Na_2\,(Al_2\ Si_3\ O_{10})\ .\ 2H_2O.$
Scolecite,	$Ca\,(Al_2\ Si_3\ O_{10})\ .\ 3H_2O.$
Mesolite,	$Ca,\ Na\,(Al_2\ Si_3\ O_{10})\ .\ 2\frac{1}{2}H_2O.$
Thomsonite,	$Na\ Ca_2\,(Al_5\ Si_5\ O_{20})\ .\ 6H_2O.$
Heulandite,	$Ca_2\,(Al_4\ Si_{14})\,O_{36}.\ 12H_2O.$
Phillipsite,	$(K,\ Ca)\ \ (Al_2\ Si_6)\,O_{12}\ 4\frac{1}{2}\ H_2O.$
Harmotome,	$(K,\ Ba)\ \ (Al_2\,Si_5)\,O_{14}.\ 5H_2O.$
Stilbite,	$(Na\ Ca)\ \ (Al_2\ Si_6)\,O_{16}.\ 6H_2O.$
Chabazite,	$(Ca\ Na)\ \ (Al_2\ Si_4)\,O_{12}.\ 6H_2O.$
Laumontite,	$(Ca,\ Na)\ \ (Al_2\ Si_4)\,O_{12}.\ 4H_2O.$
Apophyllite,	$KFCa_4\ Si_8\ O_{20}.\ 8H_2O.$
Pectolite,	$H\,Na\ Ca_2\ \ (SiO_3)_3.$
Prehnite	$Ca_2\ Al_2\ Si_3\ O_{10}\,(OH)_2.\ n\ H_2O.$

ANALCITE, ANALCIME

COMP. Na $(AlSi_2)O_6$. H_2O. Hydrous silicate of sodium and aluminium. CRYST. SYST. Isometric. COM. FORM. Usually trapezohedron crystals, also massive or granular. COLOUR. White, milk-white, greyish white, greenish, reddish white, pink. STREAK. White. CLEAV. Perfect, cubic. LUSTRE. Vitreous. FRACT. Uneven, conchoidal, brittle. H. 5·0–5·5. SP. GR. 2·25. OCCURRENCE. Occurs in certain igneous rocks, such as dolerites.

NATROLITE

COMP. $Na_2(Al_2\ Si_3\ O_{10})$. $2H_2O$. Hydrous silicate of sodium and aluminium. CRYST. SYST. Orthorhombic. COM. FROM. Prismatic crystals, usually slender to acicular, divergent. COLOUR. White, colourless, sometimes greyish, reddish or yellowish. STREAK. White. CLEAV. Perfect. LUSTRE. Vitreous to pearly. FRACT. Uneven. H. 5·0–5·5. SP. GR. 2·2–2.25. OCCURRENCE. Occurs as a secondary minerals in the amygdales in some igneous rocks, such as basalts.

STILBITE

COMP. $(Na_2\ Ca)\ (Al_2\ Si_6)O_{16}$. $6H_2O$. Hydrous silicate of calcium, sodium and aluminium. CRYST. SYST. Monoclinic. COM. FORM. Thin tabular crystals, also divergent or radiating, thin lamellar, globular, columnar. COLOUR. White, sometimes brown, yellow, red or brick red. STREAK. Uncoloured. CLEAV. Perfect. LUSTRE. Vitreous or pearly. FRACT. Uneven, brittle. H. 3·5–4. SP. GR. 2·09–2·2. OCCURRENCE. Occurs as filling minerals in cavities of basalts and lavas.

APOPHYLLITE

COMP. $KFCa_4\ Si_8\ O_{10}$. $8H_2O$. Hydrous silicate of calcium and potassium with little fluorine. CRYST. SYST. Tetragonal. COM. FORM. Crystals of varied habit, prismatic, cubic, pyramid, etc. COLOUR. White, milk white, greyish, sometimes yellowish, greenish, flesh-red or rose-red. STREAK. Colourless. CLEAV. Perfect. LUSTRE. Pearly or vitreous. FRACT. Uneven or brittle. H. 4·5–5·0. SP. GR 2·3–2·4. OCCURRENCE. Occurs as secondary minerals in rocks such as basalts, etc. and in lavas.

SCAPOLITE GROUP

The minerals of the Scapolite group crystallize in the pyramidal class of tetragonal system. The Scapolite show a gradation in physical properties from one end-member to the other. Winchell classified

the varieties of scapolites based upon the relative proportions of two molecules Me and Ma.

Marialite	to	include	Ma_{100} Me_0 to Ma_{80} Me_{20}
Dipyre	,,	,,	Ma_{80} Me_2 to Ma_{50} Me_{50}
Mizzonite	,,	,,	Ma_{50} Me_{50} to Ma_{20} Me_{80}
Meionite	,,	,,	Ma_{20} Me_{80} to Ma_0 Me_{100}

The Scapolite minerals are :

Meionite, Scapolite (Warnerite), Mizzonite (Dipyre), and Marialite.

SCAPOLITE, Wernerite

COMP. $CaCo_3$. $3CaAl_2$ Si_2 O_8. & NaCl. $3NaAlSi_3$ O_8. Silicate of aluminium, sodium and calcium with sodium chloride and calcium carbonate. COM. FORM. Prismatic crystals, also massive, granular or fibrous, columnar. COLOUR. White, grey, reddish, bluish, greenish. STREAK. Uncoloured. CLEAV. Perfect but interrupted. LUSTRE. Vitreous to pearly. FRACT. Subconchoidal, brittle. H. 5–6. SP. GR. 2·6–2·75. OCCURRENCE. Occurs in metamorphic rocks such as amphibolites, gneisses.

TIN MINERALS

Tin (Sn) is of very rare occurrence. Native tin has been reported from several localities. Tin is a greyish white metal, ductile and malleable. Tin minerals are obtained from both lodes and alluvial deposits. The tin minerals, which are obtained from lode deposits, are usually associated with copper and iron minerals, wolframe, arsenic, etc. and in alluvial deposits the tin minerals are associated with zircon, ilmenite, monazite, topaz, tourmaline, etc. generally it is found in stockworks and veins which have been derived by contact metasomatic, pneumatolytic action and disseminated replacements. In India, a few small tin deposits are found as veins and disseminations in granite and pegmatite in Hazaribagh, Ranchi and Gaya districts of Bihar.

Tin minerals are used in the manufacturing of tin plate, alloys and salts of tin are used in Calico printing, dyening, Silk-making and in the Ceramic industry. The important tin minerals :

Oxide .. .. .. Cassiterite, Tinstone, SnO_2.

Sulphide .. .. .. Stannite, Tin Pyrites, Cu_2SnFeS_4.

CASSITERITE, Rinstone, Tin Ore

COMP. SnO_2. Tin oxide. CRYST. SYST. Tetragonal. COM. FORM. Prismatic or .pyramidal crystals also massive, .fibrous. COLOUR. Brown or black, rarely red, grey, white or yellow. STREAK. White, grey, brown. CLEAV. Imperfect. LUSTRE. Adamantine. FRACT. Subconchoidal to ueven. H. 6–7. SP. GR. 6·8–7·1. VARIETY. *Stream* tin, rolled and worn cassiterite; *Wood tin,* reniform, resembling wood; *Toad's Eye Tin,* wood tin on smaller scale: OCCURRENCE. Occurs as lodes and placer (alluvial) deposits. In the lodes it is associated with ilmenite, monazite, zircon, topaz, tourmaline, etc.

STANNITE, Stannine, Tin pyrites, Bell Metal Ore

COMP. Cu_2SnFeS_4. Sulphide of tin, copper and iron with zinc. CRYST. SYST. Tetragonal. COM. FORM, Usually granular, massive, rarely in crystals. COLOUR. Steel grey, iron black, bronze. STREAK. Blackish. CLEAV. Imperfect. LUSTRE. Metallic, FRACT. Uneven. H. 3·5. SP. GR. 4·3–4·5. OCCURRENCE. Occurs in association with cassiterite, copper, silver, zinc, bismuth minerals, etc.

LEAD MINERALS

Lead (Pb) rarely occurs in native state. It is often occurs in combination with other elements as compounds. Lead is a bluish-grey, soft metal, quickly oxides when exposed in air and is easily reduced from its compound. Lead is obtained from its ores by roasting or calcining the ores first and then by smelting in reverberatory or blast furnaces. Most lead ores contain silver and zinc. Silver is obtained from lead by cupellation and zinc is separated from the lead ores by jigging floatation-process, etc.

Lead is used in the construction of accumulators, for lead piping and sheeting, cable covers, foils, amunition, as pigments, in glass making, in the rubber industry, as a flux, in medicine, etc.

The chief modes of occurrence of lead deposits are as contact metasomatic, as replacements, as veins or lodes and as disseminations. Most lead ores occurs as cavity fillings and replacements formed by low-temperature hydrothermal soultions.

The important lead minerals are as follows:

Sulphide	Galena, PbS.
Oxide	Minium, Pb_3O_4.
Carbonate	Cerussite, $PbCO_3$.
Chlorocarbonate	Phosgenite, $PbCO_3 . PbCl_2$.
Sulphatocarbonate	Leadhillite, $PbSO_4 . 2PbCO_3 . Pb(OH)_2$.
Sulphate	Anglesite, $PbSO_4$.
Basic Sulphate	Plumbojarosite, $PbFe_6(OH)_{12}(SO_4)_4$. Linarite, $(Pb, Cu)SO_4 . (Pb, Cu)(OH)_2$.
Chloro-vanadate	Vanadinite, $3Pb_3V_2O_8 . PbCl_2$ or $(PbCl)Pb_4 . (VO_4)_3$.
Chloro-phosphate	Pyromorphite, $3Pb_3P_2O_8 . PbCl_2$ or $(PbCl) Pb_4 (AsO_4)_3$.
Chloro-arsenate	Mimetite, $3Pb_3As_2O_8 . PbCl_2$ or $(PbCl)Pb_4 (AsO_4)_3$.
Molybdate	Wulfenite, $PbMoO_4$.
Chromate	Crocoisite, $PbCrO_4$.

Minerals may be described with the Lead.

Jamesonite, $2PbS . Sb_2S_3$.
Nagyagite, Sulpho-telluride of Pb and Au.
Freieslebenite, $5(PbAg_2)S . 2Sb_2S_3$.
Bournonite, $3(Pb, Cu_2)S . Sb_2S_3$.

GALENA, Galenite, Lead Glance, Blue lead

COMP. PbS. Lead Sulphide. CRYST. SYST. Isometric, COM. FORM. Usually cube, sometimes octahedral, also massive or granular. COLOUR. Lead grey. STREAK. Lead grey. CLEAV. Perfect,

cubic. 3 sets. LUSTRE. Metallic. FRACT. Even, subconchoidal, flat, H. 2·5–2·7. SP. GR. 7·4–7·6. OCCURRENCE, Occurs in association with zinc blende, occurs as contact metasomatic, as replacements, as veins or lodes and as disseminations, also occur as cavity fillings and replacements formed by low-temperature hydrothermal solutions. It occurs in Zawar of Rajasthan ; Hazaribagh and Bhagalpur of Bihar ; Drug and Bastar districts of Madhya Pradesh ; Tamil Nadu ; Jammu and Kashmir and Punjab. USE. .As a lead ore, in glass industry, in medicene, in rubber industry, for Lead pipe, etc.

MINIUM, Red oxide of Lead

COMP. Pb_3O_4. Lead oxide. CRYST. SYST. None. COM. FORM. Powdery, as crystalline scales. COLOUR. Red, orange-red, red with yellowish tint. STREAK. Orange-yellow. CLEAV. Indistinct. LUSTRE. Dull. FRACT. Uneven. H. 2–3. SP. GR. 4·6. OCCURRENCE. Occurs in association with cerussite and galena.

CERUSSITE, Ceruse, White Lead ore

COMP. $PbCO_3$. Lead Carbonate. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic or tabular crystals, granular, fibrous, massive. COLOUR. White, greyish black, grey. STREAK. Uncoloured. CLEAV. Perfect. LUSTRE. Adamantine, vitreous, resinous, pearly, sometimes submetallic. FRACT. Conchoidal. H. 3–3·5. SP. GR. 6·46–6·58. OCCURRENCE. Occurs in association with galena and anglesite, and it occurs in the oxidation zone of lead veins.

ANGLESITE, Lead vitriol

COMP. $PbSO_4$. Lead sulphate. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic, tabular crystals also a massive, granular, nodular, stalactitic. COLOUR. White with yellow, grey green tinged and sometimes blue. STREAK. Uncoloured. CLEAV. Perfect, but interrupted. LUSTRE. Adamantine, sometimes resinous or vitreous. FRACT. Conchoidal, brittle. H. 2·75–3. SP. GR. 6·3–6·4. OCCURRENCE. Occurs usually with galena.

PYROMORPHITE, Green lead ore

COMP. $3Pb_3P_2O_8 \cdot PbCl_2$. Chloro-phosphate of lead. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic, crystals, also botryoidal and reniform. COLOUR. Green, yellow and brown, with different shades. STREAK. White or yellowish white. CLEAV. Perfect. LUSTRE. Rasinous. FRACT. Subconchoidal, uneven,

brittle. H. 3·5–4. SP. GR, 6·5–7·1. VARIETY, *Mimetite*, green lead ore, *Compylite*, brown or yellowish coloured. OCCURRENCE. Occurs with other lead ores in the oxidised zone of lead veins.

CROCOISITE, Crocite, Crocoise

COMP. $PbCrO_4$. Lead chromate. CRYST. SYST. Monoclinic. COM. FORM. Prismatic crystals, also columnar and granular. COLOUR. Hyacinth red of various shades. STREAK. Orange-yellow. CLEAV. Perfect. LUSTRE. Adamantine to vitreous. FRACT. Conchoidal to uneven. H. 2·5–3. SP. GR. 5·9–6·1. OCCURRENCE. Occurs where lead minerals deposited from hot solutions containing chromic acid.

WULFENITE

COMP. $PbMoO_4$. Lead molybdate. CRYST. SYST. Tetragonal. COM. FORM. Tabular crystals, also massive, granular. COLOUR. Orange-yellow, olive-green, wax-yellow, brown. STREAK. White. CLEAV. Imperfect. LUSTRE. Adamantine or resinous. FRACT. Subconchoidal. H. 2·75–3. SP. GR. 6·7–7·0. OCCURRENCE. Occurs in lead and zinc deposits in the oxidation zone and is of secondary origin. USE. Used as an ore of molybdenum.

VANADIUM MINERALS

Vanadium (V) does not occur free in nature. It occurs in combination with other elements as compounds. Vanadium minerals occur as seams, pockets, veins and in the oxidation zone of the lead and lead-zink ores. They are associated with titanium minerals and magnetite. They are formed by weathering, residual concentrations and concentration through organisms. Few deposits are of sedimentary origin. In India, vanadiferous titaniferous magnetite are bodies occur in association with ultrabasic igneous rocks are as intrusives in South-east Singhbhum in Bihar, Mayurbhanj district in Orissa, Bhandara district in Madhya Pradesh and Krishna district in Andhra Pradesh. It is used for manufacturing special steels, high speed tool-steels, important alloys, chemicals, printing of fabrics, dying, ceramics, etc. and also as a scavenger for oxygen. The chief economic vanadium minerals are :

Sulphide	.. ..	Patronite, VS_4
Silicate	.. ..	Roscoelite, Vanadium mica.

Vanadate .. .. Carnotite, $K_2O.\ 2U_2O_8.\ V_2O_6.\ 2HO._2$. Vanadate of Uranium and Potassium.
Vanadinite, $Pb_5Cl\,(VO_4)_3$. or $3Pb_3V_2O_8.\ PbCl_2$.
Chloro-vanadate of Lead.

VANADINITE

COMP. $3Pb_3V_2O_8.\ PbCl_2$. Chloro-vanadate of lead. CRYST. SYST. Hexagonal. COM. FORM. Crystals prismatic, also in rounded forms, globules or incrustations. COLOUR. Ruby red, reddish brown, brownish yellow, straw yellow. STREAK. Yellowish white. CLEAV. Perfect in crystals. LUSTRE. Resinous. FRACT. Conchoidal, flat, brittle, uneven. H. 2·75–3. SP. GR. 6·67–7·1. OCCURRENCE. Occurs in the zone of oxidation of lead and lead-zinc deposits. USE. Used as an ore of vanadium.

TANTALUM MINERALS

Tantalum (Ta) minerals are rare and it is produced by means of the electric furnace. The tantalum minerals are white in colour, hard, ductile, having high specific gravity (16·64) and high melting point (2850°C) and is extremely resistant to corrosion. Tantalum is used for electric filaments, dental and surgical instruments, alloy steel, special steel, etc. It occurs in igneous rocks, such as granite, pegmatite, etc. in association with wolfram and tinstone. The chief tantalium mineral is :

Tantalite-Columbite, $(Fe, Mn)\ (Nb, Ta)_2O_6$. *Tantalate and Niobate of Iron and Manganese.*

TANTALITE-COLUMBITE, Tantalite-Niobite

COMP. $(Fe, Mn)\ (Nb, Ta)_2O_6$. Tantalate and niobate of iron and manganese. The mineral contains only columbium is called Tantalite and the mineral contains only niobium is called Columbite. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic or tabular crystals, also massive. COLOUR. Black, grey, brown. STREAK. Dark red to black. CLEAV. Perfect. LUSTRE. Submetallic or resinous. FRACT. Subconchoidal to uneven, brittle. H. 6. SP. GR. 5·3–7·3. OCCURRENCE. Occurs in pegmatite veins, in granite and also in certain alluvium deposits associated with wolfram and tinstone. USE. Used as a tantalum and columbium compounds.

NITROGEN MINERALS

Nitrogen (N) occur in combination in two chief types of minerals, the nitrates and the ammonium minerals. The two important nitrate minerals are :

Sodium nitrate	Soda Nitre, Chile Saltpetre, $NaNO_3$, described with sodium minerals.
Potassium nitrate	Nitre, Saltpetre, KNO_3, described with potassium minerals.

The ammonium (NH_4) minerals are :

Ammonium Chloride	Sal Ammoniac, NH_4Cl.
Ammonium Sulphate	Mascagnite, $(NH_4)_2SO_4$.
Other Ammonium minerals	Taylorite, $(NH_4)_2SO_4 . 5K_2SO_4$. Ammonium alum $(NH_4)Al(SO_4)_2 . 12H_2O$. Ammonio borite $(NH_4)_2B_{10}O_{16} . 5H_2O$.

The atmosphere contains about 78 per cent of gas nitrogen and the nitrogen forms an acid, nitric acid, HNO_3.

SAL AMMONIAC

COMP. NH_4Cl. Ammonium chloride. CRYST. SYST. Isometric. COM. FORM. Octahedron, as incrustation, usually a sublimate product. COLOUR. White, sometimes yellowish white or grey. STREAK. White. CLEAV. Perfect in crystals. LUSTRE. Vitreous or dull. FRACT. Even. H. 1·5–2. SP. GR. 1·52, OCCURRENCE. Usually a sublimate product, found as a white incrustation about volcanic fumaroles.

MASCAGNITE

COMP. $(NH_4)_2SO_4$. Ammonium sulphate. CRYST. SYST. Orthorhombic. COM. FORM. Commonly in crusts and stalactitic forms. COLOUR. Colourless, yellowish grey. STREAK. Un-

coloured. CLEAV. Perfect. LUSTRE. Vitreous. FRACT. Subconchoidal. H. 2. SP. GR. 1·76. SP. PROP. Soluble in Water, OCCURRENCE. Occurs as crusts in the neighbourhood of volcanoes and in guano deposits.

PHOSPHORUS MINERALS

Phosphorus (P) occurs as phosphates and phosphates are salts of phosphoric acid, H_3PO_4. The sources of phosphate materials are as follows: (i) Phosphate rock (nodular and hard rock deposits, soft rock deposits, pebble deposits), (ii) Phosphatic limestone, (iii) Phosphatic marls, (iv) Phosphate beds (marine), (v) Apatite deposits, (vi) Gunano deposits, (vii) Blast furnace slag (basic). Phosphatic materials contain the essential substance tricalcium phosphate. The phosphate minerals sedimentary origin are cryptocrystallise to amorphous and are fluor-apatite, hydroxy-apatite, etc. Fluorine can be replaced by chlorine, hydroxide or carbonate. The major portion of all phosphates are used as fertilisers. The chief mineral phosphates are as follows:

Amblygonite, Li (F, OH) $ALPO_4$. Lithium aluminium phosphate.

Wavellite, $4AlPO_4$. $2Al(OH)_3$. $9H_2O$. Hydrous aluminium phosphate.

Turquoise. CuO. $3Al_2O_3$. $2P_2O_5$. $9H_2O$. Hydrous aluminium oxide with copper oxide.

Libethenite, 4CuO. P_2O_5. H_2O. Hydrous copper phosphate.

Phosphochalcite, 6CuO. P_2O_5. $3H_2O$. Hydrous copper phosphate.

Torbenite, $Cu(UO_2)_2P_2O_8$. $12H_2O$. Hydrous aluminium phosphate with copper oxide.

Autonite, $Ca(UO_2)_2$ P_2O_8. $8H_2O$. Hydrous phosphate of Calcium and Uranium.

Apatite, $Ca_5(F, Cl)(PO_4)_3$. Calcium phosphate, fluoride and chloride.

Monazite, (Ce, La, Yt) PO_4. Phosphate of the cerium metals.

Pyromorphite, $Pb_5Cl(PO_4)_3$. Chloro-phosphate of lead.

Vivianite, $Fe_3P_2O_8$. $8H_2O$. Hydrous iron phosphate.

VIVVIANITE, Blue iron earth

COMP. $Fe_3P_2O_8$. $8H_2O$. Hydrous iron phosphate. CRYST. SYST. Monoclinic. COM. FORM. Prismatic crystals, also occurs as encrustations, radiating, reniform. COLOUR. White or colourless, sometimes green or deep blue. STREAK. Uncoloured, bluish

white, CLEAV. Perfect. LUSTRE. Vitreous or pearly. FRACT. H. 1·75–2. SP. GR. 2·66. OCCURRENCE. Occurs in bog iron ore, clay, mud and peat associated with copper, tin and iron ores, it is also found in fossil shells and bones.

ARSENIC MINERALS

Arsensic (As) occur in a free state in nature (native) in association with other metals. It occurs in many sulphide ores and in veins and lodes with igneous intrusions. It is steel grey coloured metal with brilliant lustre and is extremely brittle. Arsenic is generally used for making alloys, fusing glass, as a preservantive for wood and leather, in dyes, pigments, medicines, fireworks and chemicals. It is produced as a by-product in the smelting of arsenical lead, copper ores, silver, cobalt, etc. In India, arsenic minerals occur in the mica belt of Hazaribagh district, Bihar; in Darjeeling District in West Bengal; Karnataka, Uttar Pradesh, Rajasthan and Kashmir. The chief arsenic minerals are as follows:

Element	Native Arsenic, As.
Oxide	Arsenolite, As_2O_3.
Sulphides	Orpiment, As_2S_3. Realgar, As_2S_2.
Sulpharsenides	Arsenopyrite, FeAsS. Cobaltite, COAsS.
Arsenides	Niccolite, NiAs. Chloanthite, $NiAs_2$. Smaltite, $COAs_2$. Mimetite. $Pb_5Cl(AsO_4)_3$.
Arsenates	Olivenite, $Cu_3As_2O_8$. $Cu(OH)_2$. Erythrite. $CO_3As_2O_8 \cdot 8H_2O$. Annabergite, $Ni_3As_2O_8 \cdot 8H_2O$.
Sulpharsenates	Enargite, Cu_3AsS_4.
Sulpharsenites	Tennantite, $(Cu, Fe)_{12}As_4S_{13}$. Proustite, $Ag_6As_2S_6$.

BISMUTH MINERALS

Bismuth (Bi) occurs in native state and also occurs in association with silver, gold, copper, lead, etc. Bismuth is a greyish white metal. It is obtained by smelting bismuth ores in crucibles or furnaces. It is used in medicine in pigments, in glass industry and as alloy with tin, lead and mercury, etc.

Bismuth is used in medicine, in pigments, in glass industry and as alloys with tin, lead and mercury, etc. The bismuth minerals are as follows:

Element	..	..	Native Bismuth, Bi.
Oxide	..	..	Bismuth Ochre, Bi_2O_3.
Carbonate	..	..	Bismutite, $Bi_2Co_5.H_2O$.
Sulphide	..	..	Bismuthinite, Bi_2S_3.
Telluride	..	..	Tetradymite, $Bi_2(Te, S)_3$.

NATIVE BISMUTH

COMP. Bi, bismuth. CRYST. SYST. Hexagonal. COM. FORM. Crystals rhombohedra, usually massive, granular, foliaceous, pulmose or reticulated forms. COLOUR. Silver white. STREAK. Silver-white. LUSTRE. Metallic. FRACT. Brittle, sectile. H. 2–2·5. SP. GR. 9·7–9·8. OCCURRENCE. Occurs in veins in association with minerals of silver, nickel, tin, cobalt and sometimes with pyrites, quartz, chalcopyrite, etc.

BISMUTHINITE, Bismuth Glance

COMP. Bi_2S_3. Bismuth trisulphide. CRYST. SYST. Orthorhombic. COM. FORM. Usually massive, fibrous, foliated. crystals rare. COLOUR. Lead grey or tin-white, tarnish common. STREAK. Lead-grey. CLEAV. Perfect. LUSTRE. Metallic.. H. 2. SP. GR. 6·4–6·5. OCCURRENCE. Occurs in veins in association with ores of lead, tin, copper, etc. USE. Used as an ore of bismuth.

CHROMIUM MINERALS

Chromium (Cr) does not found in nature and few occur as compounds. Chromium deposits are magmatic segregations in ultrabasic igneous rocks of Archean age. They occur as lenses, masses,

veins and disseminated grains in host rocks such as dunites, saxonites, laherzolites, pyroxinites, enstatites, norites, etc., in root zones of mountains of Archean age.

The chief deposits of India are in Chaibasa in Singhbhum district of Bihar, Keonjhar, Cuttack, and Dhenkanal in Orissa, Kondapalle in Krishna district of Andhra Pradesh, Sittampundi and Chalk Hills in Salem district of Tamil Nadu; Shinduvalli and several other places in Karnataka and Ratnagiri in Maharastra.

Chromium minerals are useful for manufacturing ferrochrome, chromium chemicals, steel, stainless steel, alloy steel, refractory materials, etc.

The chief chromium minerals is chromite, $FeCr_2O_4$.

CHROMITE, Chrome Iron Ore

COMP. $FeCr_2O_4$. Oxide of chromium and iron. CRYST. SYST. Isometric. COM. FORM. Usually massive, granular, compact. COLOUR. Iron black to brownish black. STREAK. Brown. CLEAV. Imperfect. LUSTRE. Metallic or submetallic. FRACT. Uneven, brittle. H. 5'5. SP. GR. 4·2–4·85. SP. PROP. Feebly magnetic. OCCURRENCE. Occurs as an essential minerals of ultrabasic igneous rocks, such as peridotites and as an accessory minerals in some basic igneous rocks, it occurs in small grains and in detrital deposits.

MOLYBDENUM MINERALS

Molybdenum (Mo) does not occur in native state except in combination, it may be prepared by Thermit process from molybdenite or other molybdenum minerals. Molybdenum occurs in veins, pipes by pegmatitic, contact metasomatic and disseminated replacement. Occassionally it also occurs in association with graphite deposit. In India, the metal occurs in the Palni hills in the Gadavari district, Andhra Pradesh, in Choto Nagpur in Bihar, Kishengarh in Rajasthan, Assam, Tamil Nadu and Karnataka. It is used for alloy making with iron and steel, catalysts, dyes and lithographic inks. The most important molybdenum minerals are:

Sulphide	Molybdenite, MoS_2.
Molybdates	Wulfenite, $PbMoO_4$, described with lead minerals. Molybdite, $Fe_2O_3 . 3MoO_3 . 8H_2O$.

MOLYBDENITE

COMP. MoS_2. Molybdenum sulphide. CRYST. SYST. Hexagonal, COM. FORM. Usually foliated, scales or massive, prismatic or tabular crystals. COLOUR. Lead grey. STREAK. Greenish grey or bluish grey. CLEAV. Perfect. LUSTRE. Metallic. FRACT. Even. H. 1–1·5. SP. GR. 4·7–4·8. SP, PROP. Greasy feel. OCCURRENCE. Occurs in acid igneous rocks, such as granites, pegmatites is also found as a mineral in pneumatolytic contact deposits associated with wolframite, cassiterite, fluorite, etc. USE. Used as an important ore of Molybdenum.

MOLYBDITE, Molybdena, Ferrimolybdite, Molybdic Ochre

COMP. Fe_2O_3. $3MoO_3$. $8H_2O$. Hydrated iron molybdic oxide. CRYST. SYST. Orthorhombic. COM. FORM, Fibers crystal, silky, radiating, encrustation, earthy, dull. COLOUR. Sulphur yellow. STREAK. Yellowish white. CLEAV. Perfect. LUSTRE. Silky, adamantine. FRACT. Uneven. H. 1·5–2. SP. GR, 4·5. OCCURRENCE. Occurs usually in small amounts as an oxidation product of molybenite.

TUNGSTEN MINERALS

Tungsten (W) does not found in nature and few occur as compounds. Tungsten minerals occur in pegmatitic and as contact metasomatic replacement and fissure veins and placer deposits closely associated with cassiterite and acid igneous rocks. They are formed under conditions of medium to high temperature by gaseous emanations and hydrothermal solutions. Small deposits of tungsten are present in the Bankura district in West Bengal, Singhbhum district of Bihar, Nagpur district in Madhya Pradesh, at Degana in Rajasthan, Ahmedabad district in Gujarat, Kolar Gold Field in Karnataka, Chittor district of Andhra Pradesh. It is used for making important alloys, filaments for electric bulbs, electric apparatus radio, X-Ray, pigments, textiles, armour plates, guns and projectiles. Tungsten salts are used as mordants and for fire proofing proposes and tungsten carbide is used in the manufacture of cutting-tools. The tungsten minerals are :

Oxide	Tungstite, WO_3.
Tungstates	Wolfram, (Fe, Mn) WO_4. Hubnerite, $MnWO_4$. Ferberite, $FeWO_4$. Scheelite, $CaWO_4$.

TUNGSTITE, Tungstic Ochre

COMP. Wo_3. Tungsten trioxide. CRYST. SYST. Orthorhombic COM. FORM. Usually tabular, prismatic crystals, massive and bladed. COLOUR. Yellowish green. STREAK. Yellowish green. CLEAV. Perfect. LUSTRE. Sub-mettallic. FRACT. Uneven. H. 5–5·5. SP. GR. 7·1–7·9.

WOLFRAMITE, Wolfram

COMP. $(Fe, Mn) WO_4$. Tungstate of iron and manganese. CRYST. SYST. Monoclinic. COM. FORM. Usually tabular, prismatic crystals, bladed, lamellar, columnar, granular. COLOUR. Dark greyish to brownish black. STREAK. Browish black. CLEAV. Perfect. LUSTRE. Submetallic. FRACT. Uneven, brittle. H. 5–5·5. SP. GR. 7–7·85. SP. PROP. Sometimes feebly magnetic. OCCURRENCE. Occurs in granite and pegmatite veins associated with cassiterite and they are formed under pneumatolytic conditions. USE. Used as an ore of Tungsten.

SCHEELITE

COMP. $CaWo_4$. Calcium tungstate. CRYST. SYST. Tetragonal. COM. FORM. Octahedral, tabular crystals, also massive, granular, reniform with columnar structure. COLOUR. White, yellowish white. STREAK. White. CLEAV. Perfect. LUSTRE. Vitreous, adamantine. FRACT. Uneven, brittle. H. 4·5–5. SP. GR. 5·9–6·1. OCCURRENCE. Occurs in granitic and pegmatitic veins and is formed under pneumatolytic or hydrothermal conditions.

URANIUM AND RADIUM MINERALS

Uranium (U) minerals are not found in native state but it occurs in combination with other elements as compounds. It is hard white coloured metal. It is obtained by reduction of its oxide with carbon in the electric furnace.

Uranium occurs as a primary constituent of igneous rocks such as pegmatites, granites, etc, in veins associated with copper, lead and tin minerals in beach sands in certain places. In India, it is found in association with crystalline igneous metamorphic rocks, sulphide copper ores; oxidised iron ore; gold, zinc and vanadium ores. It also occurs in shades, phosphates, bituminous and lignitic deposits.

Radium (Ra) is obtained from the disintegration of uranium and uranium minerals such as pitchblende, carnotite, etc.

Uranium is used for the production of atomic power, in the manufacture of nuclear weapons, in glass staining, for glazes, in photography and in dying. Uranium minerals which contain radium are also used in the treatment of Cancer, in certain X-Ray apparatus and for luminous paint. The chief uranium minerals are:

Uranate	Uraninite, Pitchblende, $2UO_3$. UO_2.
Hydrous Vanadate ..	Carnotite, K_2O. $2U_2O_3$. V_2O_5. $2H_2O$.
Hydrous Phosphate ..	Torbernite, $Cu(UO_2)_2$ P_2O_8. $12H_2O$.
	Autuntie, $Ca(UO_2)_2$ P_2O_8. $8H_2O$.
Other minerals	Zippeite, Uraconite, Fergusonite, Brannerite, and Samarskite.

URANINITE, Pitchblende, Cleveite, Nivenite

COMP. $2UO_3$. UO_2. Uranate of uranyl. CRYST. SYST, Isometric, COM. FORM. Massive, amorphous or crypto-crystalline, boryoidal. COLOUR. Greyish black. STREAK. Black or brownish black. CLEAV. Imperfect, LUSTRE. Sub-metallic, pitch-like. FRACT. Uneven. H. 5·5. SP. GR. 6·4–9·7. OCCURRENCE. Occurs as a primary constituent of igneous rocks, granites and pegmatites.

TORBERNITE. Copper Uranite

COMP. Cu $(UO)_2$ P_2O_8. $12H_2O$. Hydrous phosphate of uranium and copper. CRYST. SYST. Orthorhombic. COM. FORM. Square tabular crystals, also micaceous, foliated. COLOUR. Green, emerald green, grass green. STREAK. Light green (paler than the colour). CLEAV. Perfect. LUSTRE. Pearly, adamantine. FRACT. Even, laminae. brittle. H. 2–2·5. SP. GR. 3·2. OCCURRENCE. Occurs with other uranium minerals, such as autonite, etc.

AUTUNITE, Lime Uranite

COMP. Ca $(UO_2)_2$ P_2O_8. $8H_2O$. Hydrous phosphate of uranium and calcium. CRYST. SYST. Orthorhombic. COM. FORM. Tabular crystals, foliated, micaceous. COLOUR. Sulphur-yellow or lemon yellow. STREAK. Yellowish. CLEAV. Perfect, basal. LUSTRE.

Pearly, sub-adamantine. FRACT. Even, laminae, brittle. H. 2–2·5. SP. GR. 3·1. OCCURRENCE, Occurs in igneous rocks associated with other uranium minerals and is of secondary origin.

CARNOTITE

COMP. $K_2O.2U_2O_3.V_2O_5.2H_2O$. Hydrous vanadate of uranium and potassium. CRYST. SYST. Orthorhombic. COM. FORM, In form of powder and in crystalline plates. COLOUR. Yellow. STREAK. Yellowish. CLEAV. Perfect, basal. LUSTRE. Pearly. FRACT. Uneven. H. 2–2·5. SP. GR. 3·1. OCCURRENCE. Occurs as powder or in crystalline plates mixed with quartzose materials.

SULPHUR MINERALS

Sulphur (S) is a yellow coloured soft mineral and a non-metallic mineral. Sulphur is one of the most important chemical minerals. It occurs as native sulphur, sulphides of base metals and sulphates of Calcium, Magnesium and rarely potassium. There is great demand for sulphur due to multifarious uses of sulphuric acid and sulphur based chemicals in industries. The fertiliser industry depends largely upon sulphur which is sometimes used directly for fertiliser and insecticides. It is also utilised for producing super-phosphates for phosphates. In India Sulphur usually recovered from sulphide and sulphate minerals. The chief sulphur minerals are:

Element	.. ..	Native Sulphur, S.
		Galena, PbS.
Sulphide	.. ..	Blende, ZnS.
		Pyrite, FeS_2.
		Cinnaber, HgS.
Sulphates	.. ..	Gypsum, $CaSo_4$. $2H_2O$.
		Anglesite, $PbSO_4$.
		Barytes, $BaSO_4$.

NATIVE SULPHUR

COMP. S. Pure Sulphur. CRYST. SYST. Orthorhombic. COM. FORM. Pyramidal crystals, also massive, and in encrustations. COLOUR. Sulphur-yellow. STREAK. Sulphur-yellow CLEAV. Imperfect. LUSTRE. Resinous. FRACT. Sub-conchoidal. H. 1·5–2·5. SP. GR. 2·7. OCCURRENCE. Sulphur is found in the crevices and craters of extinct volcanoes.

SELENIUM MINERALS

Selenium (Se) is a acidic element and belongs to the same group as tellurium and sulphur. It occurs in native sulphur and all pyritic ores.

It is used for making red glass and red enamels, as a decolo-riser of green glass, in rubber manufacture, in dyemaking, in photo-graphy and in medicine.

The chief producer countries are North America, Canada and United States.

Lead selenide	Clausthalite, PbSe.
Copper selenide	Berzelianite, Cu_2Se.
Mercury selenide	Tiemannite, HgSe.
Silver selenide	Naumannite, Ag_2Se.

TELLURIUM MINERALS

Tellurium (Te) is a semimetal. It belongs to the same group as selenium and sulphur. Very small amount of tellurium is found free in nature. It is obtained from copper-refining sludges. Most of its supply comes from the United States. It is used in rubber manu-facture, as an alloy metal, etc. The chief telurium minerals are :

Element	Native tellurium.
Oxide	Tellurite, TeO_2.
Tellurides	Tetradymite, bismuth telluride. Hessite, Silver telluride. Sylvanite, Gold and Silver telluride. Calaverite, Gold and Silver telluride. Petzite, Gold and Silver telluride.
Sulpho-telluride	Nagyagite, Gold and lead sul-pho-telluride.

NATIVE TELLURIUM

COMP. Te. Pure Tellurium. CRYST. SYST. Hexagonal, COM. FORM. Prismatic crystals, rhombohedral, also massive and granular. COLOUR. Tin white, STREAK, Tin white. CLEAV. Perfect. LUSTRE. Metallic. FRACT, Even, brittle. H. 2–2·5. SP. GR. 6·2. OCCURRENCE. Occurs with the gold ore.

TELLURITE

COMP. TeO_2. Tellurium dioxide. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic crystals, slender, spherical masses and encrustations. COLOUR. White and yellowish, STREAK, White. CLEAV. Perfect. LUSTRE. Metallic. FRACT. Even. H. 2. SP. GR. 5·9. OCCURRENCE. Tellurite results from the oxidation of tellurium or tellurides in the upper parts of veins.

TETRADYMITE, Telluric Bismuth

COMP. $Bi_2(Te,, S)_3$. Bismuth telluride. CRYST. SYST. Hexagonal. COM. FORM. Crystals rhombohedral, usually bleded, foliated, granular massive. COLOUR. Pale steel grey. STREAK. Greyish. CLEAV. Perfect, basal. LUSTRE. Metallic, splendent. FRACT. Even, laminae fexible, sectile. H. 1·5–2. SP. GR. 7·2–7·6. OCCURRENCE. Occurs in the gold-quartz veins, associated with gold tellurides, also in contact metamorphic deposits.

MANGANESE MINERALS

Manganese does not occur free in nature but in compounds. It is produced in the electric furnace and by the Thermit process. It is a light metal and pinky-grey in colour, melting at about 1260°C.

The manganese ore deposits of India are chiefly confined to the Pre-cambrian rocks of Peninsular India and occur within the Sausar Series, Aravalli Series, Champner Series, Gangpur, Series, Iron Ore Series, Khondalite Series and Dharwar System. Associated rocks of Manganese ore deposits are Gondites, Quartzites, Marbles, Mica Schists, Phillites, Limestones, Shales, Banded Ferruginous quartzites, Greenstones, Garnetiferous quartzites, garnet sillimanite gneisses and Chlorite schists.

Manganese ore is widely distributed in the globe. In India it occurs in Madhya Pradesh, Orissa, Bihar, Goa, Gujarat, Rajasthan, Andhra Pradesh, Karnataka, etc.

Manganese minerals are used for the manufacture of manganese steel, ferro alloy metals, dry batteries, glass industry, paints and

pigments, dyes, fertilizers, bromine, chlorine, oxygen, par-manganates and manganese compounds. The chief manganese minerals are:

Oxides	Pyrolusite, MnO_2
	Manganite, $MnO_2 . H_2O$
	Psilomelane, $MnO_3 . 2H_2O$
	Hausmannite, Mn_3O_4
	Braunite, Mn_2O_3
	Wad, hydrous oxide, like psilomelane
	Absolane, Cobaltiferous wad
	Franklinite, (Fe, Zu, Mn) (Fe, Mn) $_2O_4$
Carbonate	Rhodochrosite, $MnCO_3$
Sulphate	Alabandite, MnS
Silicate	Rhodochrosite, $MnCO_3$

Among the new ore minerals discovered in India Vredenburgite and Sitaparite (manganese garnet).

HAUSMANNITE

COMP. Mn_3O_4 or $MnO . Mn_2O_3$. Manganese oxide. CRYST. SYST. Tetragonal. COM. FORM.. Crystals octahedron frequently twinned, also granular massive. COLOUR. Brownish black. STREAK. Chestnut brown. CLEAV. Perfect. LUSTRE. Submetallic. FRACT. Uneven. H. 5–5·5. SP. GR. 4·85–8·86. OCCURRENCE. Occurs usually in vien associated with acid igneous rocks, and it is of primary origin.

BRAUNITE

COMP. Mn_2O_3. Manganese oxide. CRYST. SYST. Tetragonal. COM. FORM. Usually octahedral crystals, also massive. COLOUR. Brownish black to Steel grey. STREAK. Brownish black. CLEAV. Perfect. LUSTRE. Submetallic. FRACT. Uneven. brittle. H. 6–6·5. SP. GR. 4·75–4·82. OCCURRENCE. Usually secondary or primary origin, occurs in veins.

MANGANITE

COMP. MnO(OH). Hydrous manganese oxide. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic crystals, also

columnar. COLOUR. Steel grey to iron black. STREAK. Reddish brown or black. CLEAV. Perfect. LUSTRE. Submetallic. FRACT. Uneven, brittle. H. 4. SP. GR. 4·2–4·4. OCCURRENCE. Occurs in veins associated with acid igneous rocks and other manganese oxide minerals.

PYROLUSITE

COMP. MnO_2. Manganese dioxide. CRYST. SYST. Orthorhombic, COM, FORM, Pseudomorphous, usually after manganite, columnar, polianite, reniform, granular massive. COLOUR. Iron black, steel grey. STREAK. Black or bluish black. CLEAV. Imperfect. LUSTRE. Submetallic. FRACT. Brittle. H, 2–2·5. SP, GR, 4·8. SP. PROP. Soils fingers. OCCURRENCE. Occurs in irregular bodies and are of secondary origin. USE. An ore of manganese.

PSILOMELANE

COMP. A hydrous manganese oxide containing varying amounts of barium, potassium and sodium oxides. CRYST. SYST. None. COM. FORM. Massive, botryoidal; reniform, stalctite. COLOUR. Iron-black to Steel grey. STREAK. Brownish black, shinning. CLEAV. Absent. LUSTRE. Submetallic, dull. FRACT. Uneven. H. 5–7. SP. GR. 3·3–4·7. OCCURRENCE. Occurs as secondary minerals associated with pyrolusite. USE. An ore of manganese.

WAD

COMP. Variable in composition, resembling Psilomelane. CRYST. SYST. None. COM. FORM. Amorphous, reniform, earthy, compact, encrusting or as stains. COLOUR. Dull black, bluish black, brownish black. STREAK. Black. CLEAV. Absent. LUSTRE. Dull. FRACT, Uneven. H. 6. SP. GR. 3·0–4·2. SP. PROP. Soils in hand. VARIETY. *Asbolan,* wad with cobalt oxide; *Lampadite,* wad with copper oxide. OCCURRENCE. Occurs in low lying places, in dumps, results from the decomposition of other manganese minerals. USE. Used for the manufacture of chlorine and umber paint.

RHODOCHROSITE, Dialogite

COMP. $MnCO_3$. Manganese carbonate. CRYST. SYST. Hexagonal. COM. FORM Crystals rhombohedral, massive, granular, compact, botryoidal, columnar, encrusting. COLOUR. Rose-red yellowish-grey or brownish. STREAK. White. CLEAV. Perfect.

LUSTRE. Vitreous to pearly. FRACT. Uneven. H, 3·5–4·5. SP. GR. 3·4–3·6. OCCURRENCE. Occurs as a gangue mineral of primary origin in veinstone, associated with silver, lead, copper and other manganese minerals.

RHODONITE, Manganese spar

COMP. $MnSiO_3$. Manganese silicate. CRYST. SYST. Triclinic. COM, FORM. Tabular crystals, massive, compact, cleavable. COLOUR. Rose-pink, brownish red, flesh red, sometimes yellowish or greenish. STREAK. White, CLEAV. Perfect, LUSTRE. Vitreous to pearly. FRACT. Conchoidal to uneven. H, 5·5–6·5. SP, GR, 3·4–3·6. OCCURRENCE. Occurs in manganese ore deposists associated with Rhodochrosite, etc. USE. Used as an ornamental stone.

HALOGEN MINERALS

The four familiar elements, Fluorine (F), Chlorine (Cl), Bromine (Br) and Iodine (I) comprise the well marked halogen group of minerals. All halogen elements unite readily with the metals to form salts such as fluorides, chlorides, bromides, etc. are of great importance in mineralogy.

FLUORINE: Flourine does not occur in nature. It occurs as salts of hydrofluoric acid HF. The important fluorine minerals are Flour-spar, CaF_2, Cryolite, $3NaF. AlF_3$, Topaz. Apatite. It is detected in fluorides by heating with strong sulphuric acid to liberate hydrofluoric acid which etches glass.

CHLORINE: Chlorine does not occur free in nature. It occurs is combination such as Hydrochloric acid, HCL sodium chloride, potassium chloride, magnesium chloride. The important chlorine minerals are rock-salt, NaCl; Sylvine, KCL; Carnallite, KCL, $MgCl_2$, $6H_2O$; Cerargyrite, AgCl; Calomel, HgCl. Atacamite $CuCl_2$. $3Cu(OH)_2$; Pyromorphite $Pb_5Cl(PO)_3$. Chlorine is a greenish yellow gas with irritating odour and the gas is poisonous. It is fairly soluble in water.

BROMINE

Bromine occurs in nature in combined state such as bromides of sodium, silver, magnesium, calcium and potassium. The important minerals are bromyrite (AgBr) and embolite Ag(Cl, Br). Bromine is used for the preparation of tear gases, methyl bromide, medicine, photography, for treating petrol, etc.

IODINE

Iodine occurs only in the combined state in nature. The main source of iodine is the small quantity of sodium iodate, ($NaIO_3$) which is associated with chile saltpetre. Iodine is produced from sea-weed (Kelp) and organic iodine-compounds occur in milk, butter, green vegetables, cod-liver oil, etc. It is used in medicene in the preparation of certain dyes.

IRON MINERALS

Next to aluminium iron is the most abundant metal, consisting abount 4·6 percent of the earth's crust. It is found in native in meteoric masses and in eruptive rocks associated with nickel and cabalt. Metallic iron is unaffected by dry air, but oxidises to rust under the influence of moist air. Cast iron, Steel and Wrought iron are the chief forms of iron which appear in commerce. Pig iron, from which steel and grades of iron are obtained, is produced in the blast furnace bv the reduction of iron ore by coke.

In India iron ores are found in Pre-Cambrian rocks of Peninsular India. It prevails in the peninsula, where the schistose rocks of Dharwar and Cuddapah systems enclose at some places of iron deposits. The iron ore occurs as Banded-Hematite-Jasper, Banded-Hematite-Quartzite, Micaceous Hematite, Hematite-Breecia, Lateritic Hematite, Magnetite-Quartz-Schists and at some places iron ore deposits forms from the metamorphosed products of original ferruginous sands and clays. Iron ore occurs in the sideritic iron and oxidised outcrops occurring in the iron stone shales of Raniganj coal fields of Damuda Series of West Bengal. Pockets of limonitic iron ore are found in the red sandstones of Kamathi and Mahadeva age. Iron ore are also found in Deccan Traps, Upper Gondwana hematitic shares and in the Purana formations in the Himalayas.

The iron ores are used in the manufacture of iron and steel, alloys with other metals, paints etc. The following important iron minerals are as follows :

Element	.. ..	Native Iron, Fe.
Oxides	.. ..	Magnetite, Fe_3O_4. Hematite, Fe_2O_3.
Hydrated Oxides	.. ..	Limonite, $2Fe_2O_3.3H_2O$. Goethite, $Fe(OH)$. Turgite, $Fe_2O_3.nH_2O$.

Hydrated Silicate	Ilvaite, $CaFe_2(FeOH)(SiO_4)_2$.
Hydrated Sulphate ..	Copperas, $FeSO_4.7H_2O$.
Hydrated Phosphate ..	Vivianite, $Fe_3P_2O_8.8H_2O$.
Carbonate ..	Siderite, $FeCo_3$.
Sulphide ..	Pyrite, FeS_2. Pyrrhotite, Fe_nS_{n+1}

NATIVE IRON

COMP. Fe. Iron usually with nickel or other metals. CRYST. SYST. Isometric. COM. FORM. Octahedral crystals, usually massive granular. COLOUR. Iron grey. STREAK. Iron-grey. CLEAV. Perfect, cubic habit. LUSTRE. Metallic. FRACT, Uneven, Hackly. H. 4–5. SP. GR. 7·3–7·8. SP. PROP. Strongly magnetic. OCCURRENCE. Occurs as grains in some placer deposits, also found in meteorites.

MAGNETITE, Magnetic Iron Ore

COMP. Fe_3O_4. Iron Oxide. CRYST. SYST. Isometric. COM. FORM. Crystal octahedrons, dodecahedron, massive with laminated structure, granular, coarse or fine. COLOUR. Iron-black. STREAK. Black. CLEAV. Imperfect. LUSTRE. Metallic, FRACT. Subconchoidal to uneven. H, 5·5–6·5. SP. GR. 5·16–5·18, SP. PROP. Strongly magnetic. OCCURRENCE. Occurs in Archaean rocks and found as an constituent of the crystalline rocks. USE. As an Iron ore.

HEMATITE

COMP. F_2O_3. Iron Oxide. CRYST. SYST. Hexagonal. COM. FORM. Rhomboherons, columnar to granular, botryoidal, lameller. COLOUR. Iron-black to steel-grey. STREAK. Cherry-red. CLEAV. Imperfect. LUSTRE. Metallic, splendent. FRACT. Subconchoidal to uneven, brittle. H, 5·5–6·5, SP, GR. 4·9–5·3. VARIETY. *Specular Iron,* the black coloured with splendent metallic lustre in rhombohedral crystals, *compact columnar,* Micaceous (foliaceous) *Hematite, Red ocherous, Kiddney Ore, Martite, Clay-Iron Stone,* etc. USE. As an iron ore.

LIMONITE, Brown Hematite

COMP. $2Fe_2O_3.3H_2O$. Hydrous ferric oxide. CRYST. SYST. Imperfect. COM. FORM. Mammillated or stalactitic forms.

COLOUR. Brownish yellow, various shades of brown. STREAK. Yellowish brown. CLEAV. Imperfect. LUSTRE. Sub-metallic, silky, dull or earthy. FRACT. Uneven, H. 5–5·5. SP. GR. 3·6–4. VARIETY. *Bog Iron Ore, loose*, porous earthy. *Pea Iron Ore*; a pisolitic structure, *Ochres*, brown or yellow earthy forms. OCCURRENCE. Limonite is of secondary origin, results from the alteration of other iron ores or minerals.

GOETHITE

COMP. FeO (OH). Hydrous iron oxide. CRYST. SYST. Orthorhombic. COM. FORM. Prismatic crystals, fibrous, foliated, in scales, massive, reniform, stalactic with concentric and radiated structure. COLOUR. Brownish black or blood red. STREAK. Brownish yellow to ochre-yellow. CLEAV. Imperfect. LUSTRE. Subadamantine. FRACT. Uneven, brittle. H. 5–5·5. SP. GR. 4·28. OCCURRENCE. Occurs as an alteration product of sulphide minerals, such as pyrite, associated with limonite and hematite and with quartz. USE. As an Iron Ore.

SIDERITE, Chalybite, Spathose Iron.

COMP. $FeCO_3$. Iron Carbonate. CRYST. SYST. Hexagonal, COM. FORM. Crystals rhombohedral, massive, granular, botryoial, compact, earthy. COLOUR. Yellowish red, brownish yellow, greyish, greenish, ash grey, white. STREAK. White. CLEAV. Perfect. LUSTRE. Vitreous to pearly. FRACT. Uneven, brittle. H. 3·5–4. SP. GR. 3·83–3·88. OCCURRENCE. Occurs in sedimentary deposits, frequently as a vein minerals.

PYRITE

COMP. FeS_2. Iron, sulphide. CRYST. SYST. Isometric. COM. FORM, Cube and pyritohedron crystals, massive, granular, reniform, globular, etc. COLOUR. Pale brass-yellow. STREAK. Greenish black to brownish-black. CLEAV. Indistinct. sometimes distinct. LUSTRE. Metallic, splendent. FRACT. Conchoidal to uneven, brittle. H. 6–6·5. SP. GR. 4·9–5·1. OCCURRENCE. Occurs in igneous, sedimentary and metamorphic rocks of all ages. It is also considered to be of sedimentary origin. USE. An ore of copper or gold.

MARCASITE, White Iron Pyrites

COMP. FeS_2. Iron sulphide. CRYST. SYST. Orthorhombic. COM. FORM. Tabular crystals, frequently twinned, massive, radiating fibrous, globular, reniform. COLOUR. Pale bronze-yellow.

STREAK. Greyish or brownish. CLEAV. Imperfect. LUSTRE. Metallic. FRACT. Uneven, brittle. H, 6–6·5. SP. GR. 4·8–4·9. OCCURRENCE. Occurs in replacement deposits in limestones, associated with galena, sphalerite, calcite and dolomite, etc. USE. For ornaments and ore of metal.

PYRRHOTITE, Magnetic Pyrites

COMP. Fe_5S_6 to $Fe_{16}S_{17}$. Iron sulphide with variable amounts of dissolved sulphur. CRYST. SYST. Hexagonal. COM, FORM. Tabular or pyramidal crystals, massive, granular. COLOUR. Bronze-yellow, copper red. STREAK. Dark greyish black. CLEAV. Perfect, parallel to the basal pinacoid. LUSTRE. Metallic. FRACT. Sub-conchoidal to uneven, brittle. H. 3·5–4·5. SP. GR. 4·5–4·65. SP. PROP. Magnetic, varying in intensity. OCCURRENCE. Occurs in igneous rocks, such as gabbro, norite, pegmatite, associated with chalcopyrite, pyrite, magnetite, pentlandite, etc. USE. As an ore of nickel.

COBALT MINERALS

Cobalt (Co) is a maleable metal looking like nickel. It is used for alloy making, electroplating, pigments, in the ceramic industry. Cobalt occurs as veins associated with chiefly copper and silver and also from the residual weathering of basic and ultrabasic rocks. The chief producers of Colbalt are Congo, Zambia, Canada, Burma, Morocco, Finland, Russia, Chile, Germany and India. In India it occurs in thin veins and disseminations in the schists and slates in the Khetri and Babai areas of Rajasthan, Kanyakumari district of Tamil Nadu and Monipur. The cobalt minerals are as follows:

Oxide	..	Asbolite, oxide of manganese with 50% cobalt.
Arsenide	..	Smaltite, $CoAs_2$.
Hydrated Arsenate		Erythrite, $Co_3As_2O_8 . 8H_2O$.
Sulphide	..	Linnaeite, Co_3S_4.
Sulpharsenide	..	Cobaltite, CoAsS.

SMALTITE, Chloanthite, Tin White Cobalt

COMP. $CoAs_2$. Cobalt arsenide, chloanthite, nickel arsenide. CRYST. SYST. Isometric. COM. FORM. Octahedron, cube, rhom-

bohedron crystals, massive, in reticulate. COLOUR. Tin-white or steel grey. STREAK. Greyish black CLEAV. Imperfect. LUSTRE. Metallic. FRACT. Uneven, brittle. H, 5·5–6. SP. GR. 5·7–6·8. OCCURRENCE. Occurs in veins with other minerals of cobalt, nickel, sphalerite, galena, arsenopyrite, native arsenic, bismuth, etc. USE. Ores of cobalt and nickel.

COBALTITE

COMP. CoAs S. Sulpharsenide of cobalt. CRYST. SYST. Isometric. COM. FORM. Cubic and pyritohedron, commonly massive granular, compact. COLOUR. Silver-white, steel grey, greyish black. STREAK. Greyish black. CLEAV. Perfect, cubic. LUSTRE. Metallic. FRACT. Uneven, brittle. H. 5·5. SP. GR. 6–6·3. OCCURRENCE. Occurs in metasomatic contact deposits, often in quartz-rich gneiss, diopside rocks also in mica and hornblende lead, cobalt, manganese, silver and gold and also used for coinage silver ores, pyrite, pyrrhotite, molybdenite, siderite, calcite, quartz and tourmaline, etc. USE. An ore of cobalt.

NICKEL MINERALS

Nickel (Ni) is a white coloured meleable metal, which never occurs in native state. Nickel occurs in veins associated with pyrrhotite and chalcopyrite and nickeliferous serpentines. It is formed by residual concentrations of nickel silicates from the weathering of ultrabasic igneous rocks by replacement and magmatic injection. Nickel is used for alloy making with copper, chromium, aluminium, lead, cobalt, maganese, silver and gold and also used for coinage and electroplating. Nickel occurs in Canada, New Caledonia, Guatimala, U.S.S.R., South Africa, Greece, Sweden, Brazil, Norway, Burma, Finland, West Germany, Cuba, India and Nepal. In India it is found in the copper ores of Bihar, Karnataka, Tamil Nadu, Rajasthan, Manipur, Jammu and Kashmir, Orissa, Madhya Pradesh, Maharastra, Andaman islands, etc. The chief nickel minerals are as follows :

Arsenides	.. ..	Niccolite, NiAs. Chloanthite, $NiAs_2$.
Sulphides	.. ..	Pentlandite, (Fe, Ni) S. Millerite, NiS.
Silicates	.. ..	Garnierite, Genthite, } hydrated nickeliferous magnesium silicates.

Antimonide	Breithauptite, NiSb.
Nickel Blooms	Emerald Nickel, $NiCo_8$. $2Ni(OH)_2$. $4H_2O$ Nickel Vitrol, $NiSO_4$. $7H_2O$. Nickel Bloom, $Ni_3As_2O_8$. $8H_2O$.

NICCOLITE, Copper Nickel, Kupernickel

COMP. NiAs. Nickel arsenide. CRYST. SYST. Hexagonal. COM. FORM, Crystals rare, commonly massive, reniform. COLOUR. Pale copper red. STREAK. Pale brownish black. CLEAV. Imperfect. LUSTRE. Metallic. FRACT. Uneven, brittle. H. 5–5·5. SP. GR. 7·33–7·67. OCCURRENCE. Occurs in association with chloanthite, native silver, pyrite, smaltite, annabergite, chalcopyrite, etc. USE. An ore of Nickel.

MILLERITE, Capillary Pyrite, Nickel Pyrites,,

COMP. NiS. Nickel sulphide. CRYST. SYST. Hexagonal, COM. FORM. Usually in slender to capillary crystals, also in columnar, in rhombohedral crystals. COLOUR. Brass-yellow. STREAK. Greenish black. CLEAV. Perfect, LUSTRE. Metallic. FRACT. Uneven. H. 3–3·5, SP. GR. 5·3–5·65. OCCURRENCE. Occurs in capillary crystals in cavities associated other nickel minerals, various sulphides, iron ores, etc.

PENTLANDITE

COMP. (Fe, Ni) S. Nickel iron sulphide. CRYST. SYST. Isometric. COM. FORM. Masssive, granular. COLOUR. Light bronze-yellow. STREAK. Bronze-brown or black. CLEAV. Perfect, octahedral. LUSTRE. Metallic. FRACT. Uneven, brittle. H. 3·5–4. SP. GR. 5·0. OCCURRENCE. Occurs intergrown with pyrrhotite in association with chalcopyrite, pyrite, niccolite, millerite, pyrite, marcasite, etc.

ANNABERGITE, Nickel Bloom

COMP. $Ni_3As_2O_8$. $8H_2O$. Hydrous nickel arsenate. CRYST. SYST. Monoclinic. COM. FORM. Capillary crystals, massive and disseminated. COLOUR. Apple green. STREAK. Greenish-white. CLEAV. Perfect. LUSTRE. Metallic. FRACT. Uneven. H. 2·5–3. SP. GR. 3. SP. PROP. Fusible. VARIETY. Emerald Nickel (Zaratite), Nickel Vitriol (Morenosite). OCCURRENCE. Occurs in the alteration zone near the surface of nickel deposits and is of secondary origin.

GARNIERITE, Noumeite

COMP. $H_2(Ni, Mg)SiO_4 . H_2O$. Hydrated magnesium and nickel silicate. CRYST. SYST. None. COM. FORM. Amorphous, soft and friable. COLOUR. Apple-green, pale green, slightly white. STREAK. White. CLEAV. Absent. LUSTRE. Dull. FRACT. Uneven. H, 3–4. SP. GR, 2·2–2·8. VARIETY: Genthite, etc. OCCURRENCE. Occurs in serpentine rock in viens, associated with talc and chromite. USE. An important source of nickel.

PLATINUM GROUP OF MINERALS

Platinum (Pt) occurs in native state and it also occurs in combination with other elements as compounds. The platinum group of metals are platinum (Pt), rhodium (Rh), Osmium (Os), Iridium (Ir), ruthenium (Ru) and palladiumm (Pd). Platinum occurs as small grains in basic and ultrabasic igneous rocks which are magmatic segregations. It also occurs in Canada, U.S.S.R., Columbia, South Africa, Abyssinia, United States, Australia, Sierra Leone, Japan and India. It is used in the Laboratory, in the electric industry, in dentistry, and Jewellery as a catalytic agent in the manufacture of chemicals, acid making and for the manufacture of X-Ray equipment. The platinum minerals are:

Element	.. ..	Native Platinum, Pt.
Arsenide	.. ..	Sperrylite, $PtAs_2$. Cooperite, $Pt(As, S)_2$.

NATIVE PLATINUM

COMP. Platinum, Pt, alloyed with iron, iridium, rhodium, palladium, osmium, and other metals. CRYST. SYST. Isometric. COM. FORM. Usually in grains and scales, crystals rare. COLOUR. Whitish steel grey. STREAK. Whitish steel grey. CLEAV. None. LUSTRE. Metallic. FRACT. Hackly. H. 4–4·5. SP. GR. 21·46. SP. PROP. Sometimes magnetic and occasionally shows polarity. OCCURRENCE. Occurs as small grains in basic and ultrabasic igneous rocks.

SPERRYLITE

COMP. $PtAs_2$. Platinum arsenide. CRYST. SYST. Isometric. COM. FORM, In minute cubes and in combinations of cube and octahedron. COLOUR. Tin-white. STREAK. Black. CLEAV. Perfect. LUSTRE. Metallic. FRACT. Even. H. 6–7. SP. GR. 10·6. OCCURRENCE. Occurs in pyrrhotite, in gold-quartz vein, associated with covellite.

THE OPTICAL PROPERTIES OF MINERALS

The rock forming minerals such as quartz, feldspar, micas, pyroxenes, etc. are transparent in thin sections. The thin section of minerals are prepared by grinding a small chip of minerals or rock on a grinding (metal) plate of the grinding machine with the help of carborandum powder or other abrasive powder. The required thickness used for microscope study is 0·035 mm. The polished thin section of a mineral or a rock is fixed on to a glass slide (3″×1″) with the help of Canada Balsam (a viscous organic gum) and the other surface is covered with a cover glass (a piece of thin glass) and fixed with Canada Balsam. The thin section of minerals is studied under the petrological or polarizing microscope to learn the optical properties of minerals:

Abbreviation Used

Colour	..	COL.
Pleochroism	..	PLEO.
Shape & Crystal habit	..	SH. & CRYST.
Ref. Index	..	R.I.
Cleavage	..	CLEAV.
Alteration	..	ALT.
Inclusion	..	INC.
Optic Character	..	OPT. CHAR.
Interference Colour	..	INT. COL.
Birefringence	..	BIREF.
Extinction	..	EXT.
Twinning	..	TWIN.
Sign of Elongation		S.E.
Optic Angle 2V	..	OPT. ANG.

QUARTZ

COL. Colourless. PLEO. Non-pleochroic. SH & CRYST. Usually anhedral. R.I. Low. CLEAV. Absent. ALT. Absent. INC. Absent. OPT. CHAR. Anisotropic, uniaxial, positive. INT. COL. 1st order yellow, grey. BIREF. Low. EXT. Undulatory extinction. TWIN. Rarely seen. S.E. Positive.

ORTHOCLASE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually subhedral. R.I. Low. CLEAV. Perfect, 2 sets. ALT. Sometimes altered to Kaolin. INC. Absent. OPT. CHAR. Anisotropic, uniaxial, negative. INT. COL. First order grey. BIREF. Low. EXT. Inclined 5° to 12°. TWIN. Simple twinning. OPT. ANG. 60°–85°.

PLAGIOCLASE

COL. Colourless. PLEO. Non-pleochric. SH. & CRYST. Usually sub-hedral, lath shaped. R.I. Low. CLEAV. Perfect, 2 sets. OPT. CHAR. Anisotropic, biaxial, positive or negative. INT. COL. First order grey, yellow, white, etc. BRIEF. Low. EXT. Inclined 0°–70°. TWIN. Lameller twinning. OPT. ANG. 80°–105°.

MICROCLINE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually Sub-hedral. R.I. Low. CLEAV. Perfect, 2 sets. OPT. CHAR. Anisotropic, biaxial, negative. INT. COL. First order grey. BRIEF. Low. EXT. Inclined 5°–15°. TWIN. Cross-hatching. OPT. ANG. 77°–83°.

NEPHELINE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually anhedral, prismatic. R.I. Low. CLEAV. Imperfect. OPT. CHAR. Anisotropic, uniaxial, negative. INT. COL. First order grey. BIREF. Low. EXT. Parallel.

LEUCITE

COL. Water clear colour. PLEO. Non-pleochroic. SH. & CRYST. Usually euhedral. R.I. Low. CLEAV. Imperfect. OPT. CHAR. Anisotropic. BIREF. Low. EXT. Often wavy. TWIN. Complex poly-synthetic.

CORDIERITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually anhedral, pseudo hexagonal, prismatic. R.I. Low. CLEAV.

Imperfect. ALT. Usually altered into micaceous product. INC. Pleochroic halos around zircon inclusion. OPT. CHAR. Anisotropic, biaxial, negative. INT. COL. First order yellow. BIREF. Low. EXT. Undulatory extinction. TWIN. Simple twinning. OPT. ANG. 40°—80°.

SCAPOLITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually subhedral. R.I. Moderate. CLEAV. Perfect, one set. ALT. Altered to mica, quartzite, calcite, zeolite. OPT. CHAR. Anisotropic, uniaxial, negative. BIREF. Low. EXT. Distinct, parallel.

ANTHOPHYLITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral, prismatic. R.I. Moderate. CLEAV. Perfect, one set. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. Higher order colour. BIREF. Moderate. EXT. Straight. TWIN. Absent. S. E. Positive. OPT. ANG. 70°–90°.

TREMOLITE

COL. Colourless. PLEO. Non-pleochroic. SH & CRYST. Usually Usually sub-hedral (bladed, fibrous, etc), prismatic. R. I. Moderate. CLEAV. Perfect, one set. ALT. Alters to talc. OPT. CHAR. Anisotropic, biaxial, negative. INT. COL. Higher order colour. BIREF. Moderate. EXT. Inclined. OPT. ANG. 80°—85°.

APATITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. sub-hedral. R. I. Moderate. CLEAV. Imperfect. OPT. CHAR, Anisotropic, uniaxial, negative. INT. COL. First order grey. BIREF. Low. EXT. Straight.

CALCITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral. R. I. High. CLEAV. Perfect, 3 sets. OPT. CHAR. Anisotropic, uniaxial, negative. INT. COL.. Higher order. grey. pink, blue. twinkling effect. BIREF. High. EXT. Symmetrical to the cleavage traces. TWIN. Polysynthetic twinning.

KYANITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually euhedral, tabular. R.I. High. CLEAV. Perfect, 2 sets.

ALT. Usually altered to muscovite, chlorite, etc. OPT. CHAR. Anisotropic, biaxial, negative. INT. COL. Second order grey, blue, green, etc. BIREF. Moderate. EXT. Inclinic 30°. TWIN. Frequent. S. E. Positive. OPT. ANG. 82°.

SILLIMANITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually uhedral, needle shaped. R. I. High. CLEAV. Perfect, one set. INC. Inclusion of spinel, biotite, glass, etc. OPT. CHAR. Anisotropic, biaxial, negative. INT. COL. Second order yellow, brown, green, etc. BIREF. High. EXT. Straight. S. E. Positive, OPT. ANG. 20°–30°.

ZIRCON

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually uhedral. R. I. High. CLEAV. Imperfect. OPT. CHAR. Anisotropic, uniaxial, positive. INT. COL. Higher order yellow, brown, grey, green, etc. BIREF. High. EXT. Straight.

MONAZITE

COL. Yellowish or reddish brown. PLEO. Non-pleochroic. SH. & CRYST. Usually uhedral. R. I. Low, CLEAV. Imperfect. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. Higher order yellowish, reddish brown. BIREF. High. EXT. Inclined 2°–10° in longitudinal section. OPT. ANG. 6°–19°.

OLIVINE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral. R. I. High. CLEAV. Absent, cracks present. OPT. CHAR. Anisotropic, biaxial negative or positive. INT. COL. Second order yellow, green, olive green. BIREF. High. EXT. Straight. TWIN. Sometimes present. OPT. ANG. 70°–99°.

MUSCOVITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral. R. I. High. CLEAV. Perfect, one set. OPT. CHAR. Anisotropic, biaxial, negative. INT. COL. Higher order colour. BIREF. Straight. OPT. ANG. 29°–47°.

TOPAZ

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually euhedral, prismatic. R.I. High. CLEAV, Perfect, one set, ALT. Usually altered to kaolinite, sericite. OPT. CHAR. Aniso-

tropic, biaxial, positive. INT. COL. Second order, yellow, green, grey, etc. BIREF. Low. EXT. Straight. OPT. ANG. 48°–67°,

BERYL

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral, prismatic. R. I. Moderate. CLEAV, Imperfect, ALT. Usually altered to kaolin. OPT. CHAR. Anisotropic, uniaxial, negative. INT. COL. Second order green, blue, yellow. BIREF. Variable. EXT. Straight.

ZEOLITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually subhedral, trapezohedral. R. I. Moderate. CLEAV. Imperfect. ALT. Usually altered to Kaolin. OPT. CHAR. Anisotropic, uniaxial or biaxial, negative or positive. BIREF. Very weak. EXT. Straight. S.E. Negative or positive. OPT. ANG. 0°–80°.

AUGITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral. R. I. High. CLEAV. Perfect, 2 sets. ALT. Sometimes alters to hornblende, etc. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. Second order brown, yellow, etc. BIREF. Moderate. EXT. Inclined 45°–54°. OPT. ANG. 58°–68°.

DIOPSIDE

COL. Colourless, sometimes faint greenish. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral. R. I. Fairly high. CLEAV. Prismatic, two sets. OPT. CHAR.. Anisotropic. Second and third order colours, biaxial. BIREF. Fairly high. EXT. Inclined. S.E. Optically positive. OPT. ANG. Moderate, 60°.

HEDENBERGITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Sub-hedral. R. I. High. CLEAV. Prismatic, two sets. OPT. CHAR. Anisotropic, higher order colour, biaxial. BIREF. High. EXT. Inclined. S. E. Optically positive. OPT. ANG. 48°,

ENSTATITE

COL. Colourless. PLEO. Non-pleochroic. SH. & CRYST. Sub-hedral, prismatic. R. I. High. CLEAV. Perfect two sets. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. 1st order

yellow, green, grey. BIREF. Low. EXT. Straight. OPT. ANG. 60°–90°.

GARNET

COL. Pink or red. PLEO. Non-pleochroic. SH. & CRYST. Usually euhedral. R. I. High. CLEAV. Absent, traversed by branching cracks. ALT. Alters to chlorite. INC. Frequent. OPT. CHAR. Isotropic.

SPINEL

COL. Green or olive green. PLEO. Non-pleochroic. SH & CRYST. Usually euhedral or sub-hedral. R. I. High. CLEAV. Imperfect. OPT. CHAR. Isotropic.

MAGNETITE

COL. Black. PLEO. Non-pleochroic. SH. & CRYST. Usually sub-hedral. R. I. High. OPT. CHAR. Isotropic.

STAUROLITE

COL. Yellow to Brownish yellow. PLEO. Pleochroic. SH. & CRYST. Usually euhedral, prismatic. R. I. High. CLEAV. Absent. ALT. Altered to mica or chlorite. INC. Quartz common. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. First order yellowish brown. dark reddish brown, etc. BIREF. Low. EXT. Undulatory extinction. TWIN. Twinning often seen. OPT. ANG. 80°–90°.

BIOTITE

COL. Reddish brown to yellow. PLEO. Strongly pleochroic. SH. & CRYST. Usually sub-hedral, prismatic. R. I. High. CLEAV. Perfect, one set. ALT. Often alters to chlorite, etc. OPT. CHAR. Anisotropic, uniaxial, negative. INT. COL. Higher order colour. BIREF. High. EXT. Straight. OPT. ANG. 0°–20°,

HORNBLENDE

COL. Deep green to yellow. PLEO. Pleochroic. SH. & CRYST. Usually sub-hedral, prismatic. R. I. High. CLEAV. Perfect, two sets. ALT. Often alters to chlorite, etc. OPT. CHAR. Anisotropic, biaxial, negative. INT. COL. Second order green, brown, yellow, etc. BIREF. Moderate. EXT. Inclined 12°–30°. S.E. Positive, OPT. ANG. 52°–80°.

CHLORITE

COL. Green to grenish yellow. PLEO. Pleochroic. SH. & SYST. Sub-hedral, tabular. R. I. Moderate. CLEAV. Perfect, one set. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. First order grey, blue, green, brown, etc. BIREF. Low. EXT. Inclined 2°–9°. OPT. ANG. 0°–50°.

EPIDOTE

COL. Green to greenish yellow. PLEO. Pleochroic. SH. & CRYST. Sub-hedral. R. I. High. CLEAV. Perfect one set, OPT, CHAR. Anisotropic, biaxial, negetive. INT. COL. Second and third order bright colour. BIREF. High. EXT. Straight. OPT, ANG. 69°–90°.

ZOISITE

COL. Usually colourless or faintly coloured. PLEO. Sometimes pleochroic. SH. & CRYST. Anhedral, accicular, radiating. R. I. High. CLEAV. Perfect one set. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. First order yellow, blue, etc. BIREF. Low. EXT. Straight. TWIN. Polysynthetic twinning. S.E, Negative. OPT. ANG. 30°–60°.

HYPERSTHENE

COL. Reddish or greenish. PLEO. Pleochroic. SH. & CRYST. Sub-hedral, prismatic. R. I. High. CLEAV. Perfect, two sets. OPT. CHAR. Anistropic, biaxial, negative. INT. COL. Second order red, yellow, green, brown, etc. BIREF. Low. EXT. Striaght. OPT. ANG. 51°–90°.

TOURMALINE

COL. Dark brown, green, yellow, etc. PLEO. Pleochroic. SH. & CRYST. Usually sub-hedral, prismatic. R. I. High. CLEAV. Imperfect. OPT. CHAR. Anisotropic, uniaxial, negative. INT. COL. Second order green, brown, yellow, etc. BIREF. Moderate. EXT. Straight. S.E. Negative.

CHONDRODITE

COL. Colourless to yellow. PLEO. Pleochroic. SH. & CRYST. Usually sub-hedral. R. I. High. CLEAV. Cleavage absent, traversed by cracks. ALT. Usually altered into serpentine. OPT. CHAR. Anisotropic, biaxial, positive. INT. COL. Second order

yellow, brown, etc. BIREF. High. EXT. Inclined 26° -31°. TWIN. Sometimes present. OPT. ANG. 70°–90°.

MINERAGRAPHY OF ORE MINERALS

Ore minerals are best studied in reflected light using "Ore Microscopy". Ore microscope study has two aspects, (i) identification of minerals and (ii) study of textural and paragenetic relations between the minerals. Identification under the ore microscope is an important part of mineralogy. The description of opaque minerals for determinative purpose depends on certain optical and other physical properties, chief among which are the following:

1.	Composition	..	..	COMP.
2.	Crystal form and habit	..	..	CRYST.
3.	Colour	..	..	COL.
4.	Pleochroism	..	..	PLEO.
5.	Cleavage and Parting	..	..	CLEAV.
6.	Reflectivity	..	..	REFL.
7.	Hardness	..	..	H.
8.	Anisotropy	..	..	ANI.
9.	Internal Reflection	..	..	INT. REFL.
10.	Twinning and Zoning	..	..	TWIN.
11.	Associated Minerals	..	..	ASS. MIN.

HEMATITE

COMP. Iron Oxide, Fe_2O_3 ; Mn, Mg, Ti are sometimes present. CRYST. Hexagonal, rhombohedral and also occurs tabular, needle like crystals. COL. Greyish white with bluish tint. PLEO. Weak. CLEAV. Imperfect. H. High, harder than magnetite, ilmenite but is almost equally hard as the pyrite. REFL. Low. ANI. Distinct. INT. REFL. Common, particularly in poorly polished specimens. TWIN. Present, ASS. MIN. Oxides and hydroxides of Fe, Ti, Mn, Sn, etc. Pyrite and Marcasite may also be present.

MAGNETITE

COMP. Iron Oxide, Fe_3O_4 ; May contain Mg, Ti, etc. CRYST. Octahedra common, euhedral, also occurs as combinations of octahedron and rhombdodeca-hedron. COL. Grey with a brownish tint. PLEO. Weak. CLEAV. Imperfect, martitisation present. REFL. Moderately low. ANI. Isotropic. H. High. INT. REEL.

Absent. ASS. MIN. Associated with many oxides and sulphides. Commonly replaced by hematite and exsolution relationship with Ilmenite.

PYRITE

COMP. Iron sulphide, FeS_2. May contain Ni, Co, As and small amount of An. CRYST. Cubic, cube pyritohedron, generally euhedral, unless, fragmented. COL. Yellowish white. PLEO. Absent. CLEAV. Imperfect. REFL. High. ANI. Isotropic, INT, REFL. Absent. ASS. MIN. Occurs in association with most sulphides sulfo-salts, tellurides, oxides of Fe, Ti, Sn, etc.

PYRRHOTITE

COMP. Iron sulphide, Fe_nSe_{n+1}. The value of n ranges between O and Q 125. CRYST. Hexagonal, idomorphic crystals less common. But polygonal aggregates of moderate grain size are intergrowth of the hexagonal and monoclinic phases common. COL. Creamy with a pinkish brown tint. PLEO. Distinct. CLEAV. Sometimes distinct. REFL. Moderately low. H. Moderate. ANI. Very strong, in shades of grey and brown. INT. REFL. Absent. ASS. MIN. Occurs with many sulphides, sulfo-salts, tellurides, native metals, oxides of iron, tin and titinium. May contain nickel bearing sulphide pentlandite.

ARSENOPYRITE

COMP. Iron sulpharsenide, FeAsS. May contain little amount of Au and Sb. CRYST. Orthorhombic, euhedral to sub-hedral grains. COL. White with a creamy or pinkish tint. PLEO. Weak. REFL. Very high. H. High, harder than pyrrhotite, sphalerite galena, chalcopyrite and little softer than pyrite. ANI. Strong colours, reddish brown, green and sky blue. INT. REFL. Absent. TWIN. Lameller. ASS. MIN. Occurs with a number of sulfides, sulfo-arsenides, sulfo-salts, arsenides and oxides.

ILMENITE

COMP. Oxide of iron and titanium, FeO. TiO_2. May contain Mn and Mg in small proportions. CRYST. Hexagonal, trirhombohedral. Euhedral to sub-hedral prismatic grains common. COL. Brown with a pinkish tinge. PLEO. Distinct. CLEAV. Imperfect. REFL. Moderately low. H. High, slightly harder than magnetite but slightly soften than hematite. ANI. Strong, greenish to brownish grey. INT. RELF. Rare. TWIN. Lameller. ASS. MIN, Many sulphides and oxides.

CHROMITE

COMP. Oxide of iron and chromium, FeC_2O_4. May contain Al, Mg. CRYST. Cubic, octahedra, massive, granular or compact structure. COL. Darker grey to brownish grey, compared to magnetite much darker. Slightly darker than sphalerite or almost similar. Darker than ilmenite also. Ilmenite is reddish, brownish is contrast. PLEO. Absent. CLEAV. Absent. REFL. Very low. H. High, slight harder than magnetite but a little softer than Hematite. ANI. Isotropic but weak to distinct anisotropism is not rare. INT. REFL. Common (red-brown), particularly in Mg and Al-rich varieties. ASS. MIN. Ilmenite, spinel, rutile, magnetite, hematite and minerals containing platinum elements. May contain Fe and Ni-bearing sulfides in small quantities.

CHALCOPYRITE

COMP. Sulphide of copper and iron, $CuFeS_2$. CRYST. Tetragonal. Generally irregular in shape, some be polygonal. COL. Brass yellow, turnishes quickly, more yellow than pyrite. PLEO. Weak, but distinct. CLEAV. Imperfect. REFL. Moderate. H. Moderate, lower than that of pyrite, pyrrhotite, sphalerite, greater than that of galena. ANI. Weak. INT. REFL. Absent. TWIN. Lameller. ASS. MIN. Occurs with almost all sulfides, sulfo-salts, tellurides, tellurobismuthides, native metals and oxides of iron, titanium, tin and tungsten.

CHALCOCITE

COMP. Copper sulphide. Cu_2S. CRYST. Orthorhombic, fine granular and massive. COL. Bluish white, distinctly bluish in comparison to galena. PLEO. Very weak. CLEAV. Imperfect. REFL. Moderate. H. Low, greater than that of galena, but lower than that of bornite. ANI. Weak but distinct. INT. REFL. Absent. ASS. MIN. Occurs with many sulfides, sulfo-salts, tellurides,oxides, etc.

COVELLITE

COMP. Copper sulphide, CuS. CRYST. Hexagonal, usually massive. COL Deep blue with violet tint, purple red to pinkish. PLEO. Very strong. CLEAV. Perfect basal. REFL. Moderate. H, Low, slightly softer than galena and chalcopyrite. Almost similar hardness to chalcocite. ANI. Very strong, orange to reddish brown, 4 extins, "Twinkling" phenomenon in the normal variety on rotation of the stage is characteristic. INT. REFL. Absent. ASS. MIN.

Occurs in association with sulphides and sulfo-salts and also occurs as the alteration product of Cu-minerals in more common.

BORNITE

COMP. Sulphide of copper and iron Cu_3FeS_4. CRYST. Cubic, anhedral to sub-hedral grains, common occuring as aggregates of grains. COL. Pinkish brown to orange, soon tarnishes to purplish or violet. PLEO. Weak. CLEAV. May present. REFL. Moderate, H. Moderate, slightly lower than chalcopyrite but greater than galena and chalcocite. ANI. Isotropic, usually shows weak anomalous anisotropism. INT. REFL. Absent. ASS. MIN. Occurs with many other sulphides, tillurides, sulfo-salts.

SPHALERITE

COMP. Zinc Sulphide, ZnS. Usually contains Iron. Cadmium and Manganese in minor quantity. CRYST. Cubic, in granular grains or aggregates of grains. COL. Grey, sometimes with a brownish tint in oil. PLEO. Absent. CLEAV. Perfect. REFL. Low, H, Moderate, higher than that of chalcopyrite and galena but lower than that of pyrite, arsenopyrite and magnetite. ANI. Isotropic, but a weak anisotropism is not very rare. INT. REFL. Usually visible, reddish to reddish brown, yellowish to yellowish brown. ASS. MIN. Occurs with many other sulphides, sulfo-salts and oxides.

GALENA

COMP. Lead sulphide, PbS. Silver sulphide is almost always present. CRYST. Cubic, granular, grains and aggregates to irregular grains. COL. Bright white. PLEO. Absent. CLEAV. Perfect, cubic. REFL. Moderate. H. Low, softest among the common sulphides. ANI. Isotropic, weak anomalous anisotropism sometimes noticed. INT. REFL. Absent. ASS. MIN. Occurs with many other sulphides, sulfo-salts and oxides.

PYROLUSITE

COMP. Manganese dioxide, MnO_2. CRYST. May be orthorhombic, but usually pseudomorphous. Fine to coarse tabular to prismatic crystals. Radiating crystals common. COL. White with distinct yellow tint. PLEO. Distinct. CLEAV. Absent. REFL. Moderate. H. Variable. ANI. Very strong, particularly in cases of coarsely crystalline varieties. INT. REFL. Absent. ASS. MIN. Associated with other Mn-minerals and Fe-hydroxides or hematite.

PSILOMELANE

COMP. Hydrated oxide of manganese, MnO_2, H_2O. CRYST. Orthorhombic, occur as amorphous, massive, botryoidal, etc. COL. Bluish grey to greyish white. PLEO. Strong. CLEAV. Absent. REFL. Moderate. H. Very high to low. ANI. Strong, variable, INT. REFL. Brown occasionally. ASS. MIN. Commonly associated with low medium temperature Mn and Fe-oxides. Participation in colloform structures with pyrolusite and manganite is common.

BRAUNITE

COMP. Manganese oxide, Mn_2O_3. CRYST. Tetragonal, octahedral, massive aggregates, fine sub-hedral. COL. Grey with brownish tint. PLEO. Weak but distinct. CLEAV. Imperfect. REFL. Moderately low. H. High, harder than magnetite. ANI. Weak but distinct. INT. REFL. Rare. ASS. MIN, Associated with other Mn-bearing minerals. May be replaced by pyrolusite psilomelane.

INDUSTRIAL MINERALS AND ROCKS

The Economic minerals and rocks, which are utilised in the different industries, are as follows:

I. *Minerals for Iron and Steel Industries*

The raw materials needed for Iron and Steel industries are Iron Ores (Hematite and Magnetite), Coke (manufactured from Coal), Limestone (Rock), Manganese (Pyrolusite, Psilomelane), Molybdenum (Molybdenite), Cobalt (Cobaltite), Columbium (Columbite), Niobium (Niobite) and Tantalium (Tantalite).

II. *Minerals for Cement Industries*

The raw materials needed for the Cement industries are Calcitic Limestones (Rock), Clayey minerals consisting of SiO_2, Al_2O_3 and Fe_2O_3, magnesite, alkali minerals like gypsum, limestone with clay and shale, blast furnace slag, marl and clay, oyster shells and clay, etc.

III. *Minerals for Ceramic Industries*

In modern times ceramic industries have made a significant progress by producing different glass bricks, tiles, porcelains, attractive China wares from the most common minerals and rocks of the earth's crust. The chief ceramic materials are clay minerals, quartz, feldspars, bauxite, bentonite, fuller's earth, zircon, fluorspar, sillimanite, borax, magnesite, diaspore, barite, talc, cryophyllite, diatomite, lithium minerals, potash minerals, etc.

IV. *Minerals for Refractory Industries*

Refractories are the substances that can resist high heat. They are put to use in high temperature processes like metallurgical industries, ceramic industries by product, coke industry, etc. There has been a considerable demand for the use of super refractories by which use of temperatures much higher than that now generaly employed may be possible. The chief refractory materials are Clays (kaolin and fire clay), Silica (sand, topaz, sandstone, quartzite, ganister, crystobalite), High alumina (bauxite, sillimanite, kyanite, andalusite, corundum, diaspore and dumortierite), Magnesia (dolomite, magnesite, spinel, brucite, periclase), Chrome (chromite), Beryl, Graphite, Mica schists (rock), Olivine, Sericite, Talc, Soapstone, Zircon, Limestone (Rock), Rutile, etc.

V. *Minerals for Fertiliser Industries*

Fertiliser minerals include a group of unrelated minerals that are largely used as fertiliser materials in agriculture. The chief fertilizers minerals are Ammonium Rock Phosphates, Phosphorites, Gypsum, Lime, Saltpetre, Ammonium Sulphates and Sulphur, Magnesite, Dolomite, Borax, Epsomite, etc.

VI. *Minerals and Rocks for Construction Works*

The minerals and rocks are used for the construction works are as Sands (quartz). Rocks (granite. sandstone, limestones, marbles, slates, basalt, dolerite).

VII. *Minerals for Insulation and Electrical Industries*

The minerals are used as insulators and in electric industries are Asbestos minerals (chrysotile, tremolite, actinolite, anthophilite, amosite and crocidolite), mica minerals (muscovite. biotite, etc.).

VIII. *Minerals for Abrasive Industries*

Abrasives include the materials that are used for polishing, abrading, grinding, cleaning, scouring, etc. The abrasive materials includes Diamond, Corundum, Garnet, Emery, Flint, Quartzite, Quartz, Sand, Sandstone, Diatomite, Tripolite, Pumice, Volcanic Dust, Rotten Stone, etc.

IX. *Minerals for Chemical Industries*

Minerals which are used in the chemical industries are as follows: Sulphur, Pyrites, Barites, Fluorspar, Salt and Saline products.

X. *Minerals used for Pigments*

Mineral pigments are used in the paint and varnish industries and are also used to give colours to cement, linoleum, rubber, mortar, plastic and other materials. The mineral includes white clay, kaolin, chalk, gypsum. baryte, talc, limestone. marble. cryolite. black shale, slate, graphite, lamp black, pyrolusite, psilomelane, hematite, goethite. iron oxides, red ochre, red slates and shales, chromate, cadmium sulphide, selenium iron oxide, calcium sulphate, hematite, magnetite. chlorite rocks, greenstones, epidote sandstones, serpentine, green slate, azurite, etc.

XI. *Mineral and Fossil Fuel*

Minerals occur naturally in the earth's crust which consist chiefly of organic hydrocarbons which is used for producing heat energy either by means of the release of its chemical energy by com-

bustion or its nuclear energy by nuclear fusion : Liquid fuel (Petroleum, fossil fuel), Solid fuel (Coal, fossil fuel) and Mineral fuel radioactive minerals : monazite, thorite, autunite and carnotite.

XII. *Minerals used as Precious and Semi-Precious Stones*

The Precious Stones are diamonds, rubies, sapphire and emeralds and the semi-precious stones like agate, amethyst, onyx, carnelian blood-stone, opal, moonstone, spinel, topaz, garnet, zircon, chrysoberyl, peridot, lapis lazuli and turquoise. ..

XIII. *Minerals used as Medicine*

The minerals have been used in Indian medicines since ancient times. The different curative powers of minerals claimed in Indian medicine have to be substantiated by modern medical research. A list of minerals used in Indian medicine was presented by Ray (1956), and Gupta (1956), Roy and Subbarayappa (1976) and Murthy (1977, 1979, 1983).

(i) Minerals used by Ayurvedist are alum, chalk, mineral bitumen, iron, copper, murcury, silver, gold, evaporites, rock salt, glassy minerals, sulphur, yellow orpiment, blue and green vitrols, yellow and red ochres, black sand, red clay, gems, iron ores, pyrites, etc.

(ii) *Native elements* like iron, zinc, lead, gold, silver, copper, tin, bismuth and mercury have been used in the preparation of Indian medicnes.

(iii) *Precious and semi-precious stones* like diamond, sapphire, ruby-corundum, peridot, jade, jadeite, lizardite, topaz, garnet, zircon, chrysoberyl, nepheline, feldspars, moonstones, lode stone, rock crystal, etc. have been employed in different medical prescriptions.

(iv) *Other minerals* used in Indian medicines are red-ochre, sulphur, realgar, orpiment, hematite, stibnite, magnesite, cinnabar, arsenic, iodine minerals, bromine minerals, messicot, sal Ammoniac, etc.

(v) The different curative powers of minerals claimed in Indian medicines are (a) *ashes of fluorspar* used to cure poisoning; (b) *ashes of biotite* used to cure bronchites, T.B., leprosy; (c) *mineral bitumen* used to cure skin deseases, heart ache; (d) *Copper minerals* used to cure acidity and genital deseases; (e) *red ochre* used to cure vomiting, blood dysentry, eye deseases; (a) *Stibnite* used to cure eye deseases; (g) *Orpiment* used to cure chronic bronchites; (h) ashes of bismuth, calamine, sulphur, etc. used to cure T.B., V.D., injuries, skin deseases, typhoid, etc.

QUESTIONS

PHYSICAL MINERALOGY

1. What are minerals? Describe briefly the physical properties of minerals with suitable examples.

2. Define the term mineral and hence write down whether the following can be regarded as mineral or not :

Snow, Sea-Water, Common salt obtained by boiling sea water, Human bone, Sugar Crystals, Sulphur deposit not around a volcano, water of Lake Chilka, Quartz in a granitic rock, window glass, coal, ice obtained through cooling of water in a refrigerator, Shell material of a brachiopod, Sea-beach sand, brick, sulphur in a rock, Sulphur obtained by burning pyrite.

3. Say, with reasons, which one of the given pairs can be regarded as a mineral and which one cannot be :

(i) Sulphur lenses in metamorphic rock and sulphur obtained by burning pyrite (ii) Snow on the hill slopes of Mt. Everest and ice inside refrigerator. (iii) Common salt bed in sedimentary rock and the same obtained by boiling sea water. (iv) Calcite in marble and the same in brachiopod shell (v) Sea water and water inside a green coconut. (vi) Metallic silver associated with gold in a quartz vein and that obtained from argentite.

4. What is a mineral? How are the minerals classified on the basis of composition ? What do you mean by rock forming minerals? Give examples of these rock forming minerals and name the rocks in which they are found.

5. (i) Which plate will you pick up for examining streak of a mineral-dull iron plate, shining brass plate and a dull white porcelain plate? (ii) A mineral is not scratched by iron plate but scratches brass plate. What is its hardness? (iii) A mineral shows 4 cleavage planes that are all mutually parallel. How many sets of cleavages does it possess ?

6. (a) Find out the correct answer for the following statement and illustrate your answer with reason : (a) Lustre is dependent on : Hardness/Refractive Index/Colour/Specific gravity/Thickness. (b) Name only one essential chemical test with corresponding observations to be performed to detect the major radicals either of apatite or of arsenopyrite (c) Name only one test with corresponding result by which you can distinguish the underlined mineral from the rest. Wolframite, Hematite and Magnetite. (d) If sulphur obtained by burning pyrite is a mineral or snows on Mount Everest are minerals.

7. A mineral grain shows 15 cleavage planes in total of which 8 are mutually parallel among themselves, and the rest 2, similarly parallel among themselves but non-parallel to either of the two above. Give the number of cleavage sets with the numbers of cleavage planes per set.

8. (a) Name two minerals that have identical chemical composition but different hradness. Mention the hardness against each. (b) why is the specific gravity of quartz definite (2.65) where as that of pyroxene is variable (3.2 to 3.6) ?

9. Explain the following:

(i) It is difficult to study fracture for galena. (ii) Streak of beryl cannot be studied by rubbing it on a streak plate. (iii) Is ice in a refrigerator a mineral ? If so why ? (iv) Is quartz in beach sand a mineral ? If so give reasons. (v) It is very difficult to study fracture for calcite. (vi) Quartz Yields no streak on streak plate. (vii) Diamond is much harder than graphite, though both are carbon. (viii) Barite has specific gravity higher than that of Calcite, though both are sulphates. (ix) Amphibolite yields needle-shaped individuals on hammering. (x) Bauxite shows no cleavage.

10. (a) Rearrange the following two columns into correct statements :

Quartz	:	shows 2 sets of cleavage at right angles.
Muscovite	:	shows botryoidal structure.
Psilomelane	:	has no cleavage.
Feldspar	:	can be split into very thin flakes.

(b) Select the most appropriate answer:

(i) A mineral scratches brass plate. The next material to be taken is pocket knife/Lens/Streak plate. (ii) Streak obtained by : counting number of cleavage plane/rubbing on a hand, unglazed porcellain plate/trying to produce a scratch mark on a glass plate. (iii) A mineral breaks along 6 planes that are all parallel. It shows then : even fracture/hexagonal symmetry/one set of cleavage. (iv) Hardness of a mineral is studied by hammering/by scratching some standard materials with smooth surface/by rubbing several times on streak plate. (v) A mineral breaks into two fragments one showing a smooth concave and other convex surface. Its fracture is conchoidal/ it is hollow/it has good cleavage. (vi) A mineral scratches streak plate. Its hardness is 2.5 to 3.5/ its streak is not obtainable.

11. Name the following:

(a) Mineral yielding cherry red streak. What is the colour. (b) Translucent white mineral with moderate specific gravity. What is its chemical composition ? (c) Mineral showing different hardness with changing direction ? What is its structure. (d) Mineral showing fixed chemical composition. What is the nature of its cleavage ? (e) A non-crystalline mineral what is its structure (f) Mineral with perfect cubic cleavage. What is its lustre ? (g) Has no cleavage. What is its lustre ? (h) Yields fracture with much difficulty. What is its hardness. (i) Can be split into very thin flakes by hand. What is its colour ? (j) Can write on paper. What is its colour ? (k) Has separable fibrous structure. (1) Effervesces vigorously in lump with cold dil. HCL. (m) Shows perfect cubic cleavage. What is its colour ? (n) Has soapy feel : What is its lustre ? (o) Is equidimen-

sional, transparent pink with prominent development of crystal faces. What is its cleavage ? (p) Three minerals with hardness less than 4. (q) Three minerals having three sets of cleavages. (r) Three minerals in which colour differs from the streak. (s) Five chief rock forming minerals. (t) Has different values of hardness in different crystallographic directions. (u) Name a green mineral having same streak. (v) Name polymorphs of potash feldspar. (w) Name a mineral having three sets of cleavage. (x) Name a mineral having bladed structure and hardness varying from 4-7.

12. Fill up the blanks :

(i) ...... Shows one set of highly perfect cleavage. (ii) ...... Shows four sets of cleavage. (iii) ...... Yields hackly fracture (iv) ...... shows botryoidal structure (v) ...... can be scratched by finger nail. (vi) ...... is strongly magnetic in lump. (vii) ...... has low sp. gravity though it is black. (viii) ...... is a sulphate pearly lustre. (xi) ...... is non-crystalline. (xii) ...... has no pearly lustre. (xi) ...... is non-crystalline. (xii) ...... has no cleavage. (xiii) ...... gives cherry-red streak. (xiv) ...... though black gives uncoloured streak. (xv) ..... highly perfect one set of cleavage. (xvi) ...... is hardest of all minerals. (xvii) ...... Shows varying hardness in varying direction. (xviii) It is extremely difficult to obtain fracture for ..... (xix) ...... has two sets of cleavage nearly at right angles. (xx) ...... Shows variation in lustre with variation in thickness. (xxi) .... . sometimes shows non separable fibrous structure. (xxii) ...... shows good octahedral cleavage. (xxiii) ...... has streak darker than its colour in lump. (xxiv) Asbestos breaks yielding ...... fracture. (xxv) Galena is an ore of ....

13. Write notes one :

(a) Isomorphism (b) Moh's Scale of hardness (c) Streak (d) Variables of lustre (e) Amorphous (f) Parting.

14. Distinguish between :

(i) Cleavage and parting (ii) Crystalline and non-crystalline. (iii) Schillerisation and Metallic lustre. (iv) Colour and Streak (v) Cleavage of Calcite and of Galena. (vi) Colour of biotite in lump and in their flakes. (vii) Lustre of galena and of hematite. (viii) Streak of pyrite and of chalcopyrite. (ix) Cleavage and fracture. (x) Amorphous and crystalline states of matter.

15. How would you distinguish between the following pairs of minerals on the basis of Physical Characters ?

(a) Quartz and Feldspar (b) Hematite and Magnetite (e) Pyrolusite and Psilomelane (d) Pyrite and Chalcopyrite (e) Feldspar and Fluorite (f) Chromite and Hematite (g) Biotite and Muscovite. (h) Sulphur and Orpiment (i) Graphite and Galena (j) Malachite and Sulphur (k) Beryl and Apatite (l) Calcite and Barite (m) Orthoclase and Rhodochrosite (n) Halite and Fluorite (o) Kyanite and Sillimanite (p) Galena and Sphalerite (q) Fluorspar and Rock Salt (r) Psilomelane and Goethite.

16. Give the physical properties, chemical composition and mode of occurrence :

Diamond, Hematite, Barytes, Gypsum, Galena, Pyrite, Gold, Pyrolusite, Magnetite, Graphite, Calcite, Sphalerite, Stibnite, Fluorite, Magnesite, Cryolite, Aragonite Chalcopyrite, Gypsum, Apatite, Pyrolusite, Halite, Sulphur, Realgar, Braunite, Cassiterite, Corundum, Azurite, Talc, Cinnabar, Siderite, Ilmenite.

17 Describe the physical properties and chemical composition of rock forming minerals group :

(a) Quartz Group (b) Feldspar Group (c) Pyroxene Group (d) Amphibole Group (e) Mica Group.

18. How would you distinguish between the following pairs of minerals on the basis of physical characters ?

(a) Quartz and Feldspar (b) Hematite and Magnetite (c) Pyrolusite anl Psilomelane (d) Pyrite and Chalcopyrite (e) Feldspar and Calcite (f) Quartz and Fluorite (g) Galena and Magnetite (h) Calcite and Barite (i) Psilomelane and Goethite (j) Kyanite and Sillimanite (k) Sulphus and Orpiment (l) Feldspar and Fluorite (m) Chromite and Hematite (n) Muscovite and Biotite.

19. State the Chemical Composition, important physical properties and chief uses of the following minerals :

(a) Sphalerite (b) Hematite (c) Garnet (d) Gypsum (e) Fluorite (f) Quartz (g) Graphite (h) Psilomelane (i) Muscovite (j) Halite (k) Chalcopyrite.

20. A mineral grain show 15 cleavage planes in total of which 8 are mutually parallel among themselves and the rest 2, similarly parallel among themselves but non parallel to either of the two above. Give the number of cleavage sets with numbers of cleavage planes per set.

21. Name the following minerals :

(a) Name three minerals with hardness less than 4.

(b) Name three minerals having three sets of cleavages.

(c) Name three minerals in which the colour differs from the streak.

(d) Name five chief rock forming minerals.

22. Explain the following :

(i) It is very difficult to study fracture for calcite.

(ii) Quartz yields no streak on streak plate.

(iii) Diamond is much harder than Graphite. though both are carbon.

(iv) Barite has sp. gravity higher than that of Calcite, though both are sulphates.

23. Distinguish between :

(a) Cleavage and parting (b) Colour and streak (c) Schillerization and metallic lustre (d) Cleavage of calcite and galena (e) Colour of biotite and in their flake (f) Lustre of galena and of haematite (g) Streak of pyrite and chalcopyrite (h) Cleavage and Fracture.

24. (a) How would you distinguish between a rock and a mineral ?

25. Name a mineral that :

(i) Shows perfect cubic cleavage what is its colour ? (ii) Can be split into very thin flakes and is transparent and colourless what is its hardness ? (iii) has soapy feel. What is its lustre ? (iv) is equidimensional, transparent pink with prominent development of crystal faces. What is its cleavage ?

26. Say, with reasons, which one of the given pairs can be regarded as a mineral, and which one cannot be :

(i) Sulphur lenses in metamorphic rock and sulphur obtained by burning pyrite ;
(ii) Snow on the hillslopes of Mt. Everest and ice inside refrigerator ?
(iii) Common salt bed in sedimentary rock and the same obtained by boiling sea water.
(iv) Calcite in marble and the same in a brachiopod shell.
(v) Sea water and water inside a green coconut.
(vi) Metallic silver associated with gold in a quartz vein and obtained from aragonite.

27. Write notes on :

Hardness, Streak, Moh's Scale of Hardness, Structure, Cleavage, Colour, Fracture, Lustre.

28. Correct the Statements :

(i) 'Metallic lustre' is given by quartz/tourmaline/galena.
(ii) 'Cherry red' coloured streak is given by Graphite/bauxite/hematite.
(iii) The formula of pyrite is FeS_2/$CaCO_3$/PbS.
(iv) 'Mottled extinction' is given by muscovite/quartz/hornblende.
(v) 'Lameller twinning' is given by plagioclase/diopside/biotite.
(vi) Chalcopyrite often found with biotite/gypsum/pyrite.
(vii) Hornblende, belongs to pyroxene group/amphibole group/mica group.
(viii) Pisolitic structure, can be observed in bauxite/chalcopyrite/tourmaline.
(ix) Zinc can be obtained from muscovite/augite/sphalerite.
(x) The colour of sulphur is green/yellow/colourless.
(xii) Select the most appropriate answer :
(a) A mineral scratches brass plate. The next material to be taken is : Pocket knife/Lens/Streak plate.
(b) Streak is obtained by : Counting number of cleavage plane/rubbing on a hard unglazed porcelain plate/trying to produce a scratch mark on a glass plate.
(c) A mineral breaks along 6 planes that are all parallel It shows then : even fracture/hexagonal symmetry/one set cleavage.

(d) Hardness of a mineral is studied: by hammering/by scratching some standard materials with smooth surface/by rubbing saveral times on streak plate.

(e) A mineral breaks into to fragments one showing a smooth concave and other convex surface its fracture is : conchoidal it is hollow/it has good cleavage.

(f) A mineral scratches streak plate is : its hardness is 2.5 -3.5/its streak is absent/its streak is not obtainable.

(g) Say with reasons, whether the following may be regarded as mineral or otherwise :
quartz in granitie rock ; Window glass ; Sulphur around a Volcanic Crater ; Coal.

29. Name one mineral that :
(i) has no cleavage.
(ii) has two widely different values of hardness along two different crystallographic directions.
(iii) has separable fibrous structure.
(iv) can write on white paper.
(v) effervesces vigorously in lump with cold dil HCL.

30. State the chemical composition, important physical properties and chief uses of the following minerals :
(a) Sphalerite (b) Hematite (c) Garnet (d) Gypsum (e) Fluorite (f) Quartz (g) Graphite (h) Psilomelane (i) Garnet (j) Muscovite (k) Halite (l) Chacopyrite (m) Galena

31. Fill up the gaps :
—— though dark black has low sp. gravity.
(i) —— Shows one set highly perfect cleavage.
(ii) —— Shows vitreous lustre.
(iii) —— Can be scratched by finger nail.
(iv) —— has 2 sets perfect cleavage.
(v) —— gives streak darker than colour.
(vi) —— is strongly magnetic in lump.
(vii) —— does not readily yield fracture.
(viii) —— has no cleavage.
(ix) —— has low sp. gravity though it is black.
(x) —— has fixed chemical composition.
(xi) —— Shows pearly lustre.
(xii) The extinction angle of augite is ——.
(xiii) The common form of garnet is ——.
(xiv) Form the point of view of atomic structure, amphibole is a ——.
(xv) Composition plane is albite twin is ——
(xvi) —— is a sulphate mineral.
(xvii) Shows very good double refraction.
(xviii) —— Yields 3 sets perfect cleavage.
(xix) —— is the hardest of all mineral.
(xx) Cherry red streak is shown by ——.
(xxi) —— has two different values of hardness in two different crystallographic directions.

(xxii) —— Shows perfect cubic cleavage.
(xxiii) —— Shows botryoidal structure.
(xxiv) —— is magnetic in lump.
(xxv) —— Shows pisolitic structure.
(xxvi) —— is golden yellow in colour.
—— Shows variation in lustre with changing direction.
(xxvii) —— has adamantine lusture.
(xxviii) —— has highly perfect one set cleavage.
(xxix) —— has a soapy feel.
(xxx) —— Shows four sets of cleavage.
(xxxi) —— Yields hackly fracture.
(xxxii) Streak is darker then colour in lump for——.
(xxxiii) —— has golden yellow colour.
(xxxiv) Asbestos breaks yielding —— fracture.
(xxxv) —— can be scratched by no mineral.
(xxxvi) —— is an example of non-crystalline state of minerals.
(xxxvii) Muscovite shows —— lustre.
(xxxviii) —— Shows two sets of cleavage almost at right angle.
(xxxix) —— Shows variation in lustre with variation in thickness.
(xxxx) —— Sphalerite shows —— lustre.
(xxxxi) —— has streak darker than its colour in lump.
(xxxxii) Rhodochrosite is always —— in colour.
(xxxxiii) —— Shows prominent nodular structure.
(xxxxiv) —— Shows good octahedral cleavage.
(xxxxv) —— Sometimes shows nonseparable fibrous structure.

32. (a) Name a green mineral having same streak.
(b) Name polymorphs of potash feldspar.
(c) Name a mineral having 3 sets of cleavage.
(d) Name a mineral having bladed structure and hardness varying from 4—7.

33. (a) Distinguish between cleavage and fracture Or between colour and tarnish.
(b) Is ice in a refrigerator a mineral ? If so why ?
(c) Is quartz in beach sand a mineral ? If so give reasons.
(d) State with reasons :
if Sulphur obtained by burning pyrite is a mineral Or
Snows on Mount Everest are minerals.

34. (a) State with reasons, whether the following may be regarded as minerals or not : Snow, quartz in a rock Carbon obtained by burning of wood, sulphur around a volcano, water of lake chilka.
(b) Which plate will you pick up for examining streak of a mineral—dull iron plate, shining brass plate and dull white porcelain plate ?
(c) A mineral is scratched by iron plate but scratches brass plate. What is its hardness ?
(d) A mineral scratches iron-plate. Which plate is to be taken next to study its hardness ?

23. (a) If a light ray travels parallel to the ... isometric crystal, in what direction will ...
(b) What is the difference between the pat... and a light ray ?
(c). How do light waves behave as they a... (i) transparent body (ii) opaque body
(d) What is phase of vibration ? How the... between two light waves may be expr... with diagrams.

24. What is meant by 'interference colour' of a... are such colours classified ? What is the basis of th...

25. How will you determine the vibration dire... matic section of hornblende with the help of its inter...

26. Fill up the blanks ;
(i) The extinction angle of augite is ———
(ii) Composition plane in albite twin is ———
(iii) ——————— Shows very good double ref...

27. Write a note on the optical characters of t... of minerals.

28. What is polarised light ? How does it diff... light ?

29. What is meant by 'interference colour' of a... are such colours classified ? What is the basis of t... How will you determine the vibration directions of a... of hornblende with the help of its interference colo...

30. Explain the causes of extinction of miner... microscope. How will you determine the extinction... blende under microscope ?

31. Describe the optic axial figure of a biaxia... can you determine the optic sign of the mineral with...

32. (a) If a light ray travels parallel to the y... isometric crystal, in what direction will it vibrate ? ... difference between the path of a light wave and a lig... do light waves behave as they are incident on a (i) ... (ii) opaque body. (d) What is phase difference be... waves may be expressed ? Explain with diagrams.

4. Give the symmetry elements of the normal class of Orthorhombic system. Name one mineral of this system. Draw a sketch stereogram to illustrate your answer.

5. What are the possible elements of symmetry in crystals? Write down in a tabular form the symmetry elements of normal classes of different crystal systems.

6. Classify the crystals into systems. Enumerate the nature and arrangement of crystal axes and characteristic symmetry elements of the different crystal systems. State the crystal systems of the following minerals: Magnetite, Gypsum, Sulphur, Iceland Spar.

7. What is meant by symmetry of crystals? What are elements of symmetry? State the symmetry elements of the normal class of tetragonal system. Draw a neat sketch of a simple tetragonal crystal indicating its crystallographic axes.

8. Describe only the axial and symmetry elements of normal class of Orthorhombic or Hexagonal system, and name one mineral crystallising under the given system.

9. Write down the common forms developed under Normal class of Tetragonal system mentioning all the relevent points.

10. To which crystal systems do the following crystals belong and name the crystal and crystal class :

(a) A crystal having only one plane and one two fold axis, and a centre of symmetry. (b) A crystal having four-fold axes of symmetry. (c) A crystal having a centre of symmetry. (d) A crystal having four planes of symmetry meeting along one axis of symmetry., (e) A crystal having one axis of symmetry along which three planes of symmetry intersect. (f) A crystal having one axis of hexagonal symmetry. Depict the above characters by sketch stereographic projections. (g) One axis of six fold symmetry. What are the number of planes of symmetry? (h) Each of the three crystallographic axes of binary symmetry. What are the axial angles? (i) Three axes of four fold symmetry. How are crystallographic axes named? (j) Four vertical planes of symmetry, each perpendicular to another common plane of symmetry; (k) Three planes of symmetry, perpendicular to each other and hence mention. (l) Other symmetry elements if present. (m) Axial elements, with a neat, labelled sketch. (n) Only one tetrad, perpendicular to a horizontal plane of symmetry. What are the other symmetry elements? (o) Only one plane of symmetry. What are the axial angles, and how are the crystallographic axes named? (p) Three planes of symmetry that are mutually perpendicular. What will be number of faces developed under the form (111) and what are their indices?

11. Distinguish between :

Holohedral and hemihedral form; Axes of symmetry and crystallographic axes; Trapezohedron and Trisoctahedron; Cube and Rhombohedron; Hemimorphic crystal and Hemihedral form; Octahedron and hexoctahedron; Prism of first order and prism of 2nd order in hexagonal system; Plane of symmetry and [illegible]

prism ; Axis of symmetry and crystallographic axis ; Crystal and crystallite. Simple form and combination forms ; Axial plane and plane of symmetry.

12. Write notes on :

Miller indices, Twinning in crystal, Plane of symmetry, Octahedron, Axis of symmetry, Dodecahedron, Centre of symmetry, Symmetry, Crystal axis, Pedion, a crystal class, amorphous matter, plane of twinning, S———— Projection, Interfacial angle, contact Goniometer, Indices in crystallography. Analyser of a microscope, Cross-line ; Constancy of inte facial angles of crystals ; Crystallographic axes, closed form ; Parameter ; Cube ; Prism, Tetragonal dipyramid.

13. Draw a sketch of each of the following forms and name one ——— each :

Pyramid, Prism, Rhombohedron, Tetrahedron, Pinacoid, Pedion.

14. (a) Find out the respective indices of faces, the parameter being (i) 2a : 16 : ½c ; (ii) ½a : ∞b : ½c.

(b) Find out the parameter of the given faces :

321, 102, 211, 210, 001.

15. Give the following data for a crystal

$110 \wedge 1\bar{1}0 = 72°30'$

$001 \wedge 100 = 90°$

Name the crystal system stating reasons. Describe the axial ——— of the system, symmetry elements and common forms under ———nal class. Name two common minerals crystallising under the given class.

16. (a) Describe the number of faces, with face symbols and form name under (101) in normal class of isometric, tetragonal, orthorhombic and monoclinic systems.

(b) On a stereogram represent the following symmetry elements and name the corresponding class any system :

(1) $3A_4 ; 4A_3 ; 6P$ (2) $1A_4 ; 4A_2$ (3) $3A_2$

17. (a) From the given indices of the following faces, find out the parameter : 301, 132, 213.

(b) Given a : b : c : : 8 : 1 : 1·2 and b=10 cms., (i) find out the actual length of intercept of the faces 234, 412 and 123 with the crystallographic axes ; (ii) find out indices of faces that intersects axes 'a' 'b' & 'c' at distances (α) 2 cms, 3 cms and 3 cms, & (β) 4 cms, 4 cms & 4 cms respectively.

(c) Find out the zone-axis of faces 011—023—052—001 and state, with reasons, whether the following faces lie in the said zone or not : 203 ; 021 ; 111.

(d) Find out number of faces under (i) from (100), given the axes are all equal and interchangeable ——— axes of binary symmetry. (ii) form (111) ——— three axial planes is a plane of symmetry. (iii) ——— vertical axis is axis of

tetragonal symmetry, and not interchangeable with the horizontal axes.

(e) Describe the axial and symmetry elements as also the common forms developed under normal class of either Isometric or Tetragonal system. Name two minerals crystallising under the same.

(f) Find out indices from the given parameter :

(i) $1a : 2b : \frac{1}{2}c$. (ii) $\frac{1}{2}a : \infty b :$ . .

(iii) $\frac{1}{3}a : \frac{1}{2}b : 1c$.

(g) Find out parameter from the given indices :

(i) 214 (ii) 203 (iii) 321

18. Fill up the blanks :

(i) Pinacoid consists of ——— faces (ii) Crystals under Normal class of ——— system have 3 planes of symmetry. (iii) 201 is a face that is parallel to ——— axis. (iv) ——— is a form consisting of twelve faces. (v) ——— is an example of a closed form consisting of six faces. (vi) ——— of symmetry divides a crystal into two similar halves, one half being mirror-image of the other. (vii) ——— system shows maximum order of symmetry. (viii) ——— is an open form consisting of two like faces. (ix) Rhombdodecahedron is a form under ——— system. (x) ——— System shows minimum symmetry element. (xi) In a crystal, tetrad is maximum ——— in number. (xii) A closed form consisting of eight like faces is called ——— in isometric system. (xiii) An open form consisting of six like faces lying in a zone and related to one another by one hexad is named ———. (xiv) A ——— is a closed form consisting of forty eight like faces. (xv) A ——— is an open form consisting of two parallel faces. (xvi) A ——— is a closed form consisting of twelve faces. (xvii) A—embraces maximum number of faces under tetragonal system. (xviii) 'b' axis is called ——— axis in orthorhombic system. (xix) ——— of symmetry divides an ideally developed crystal into two equal and equally placed haves. (xx) For a —— axis, minimum amount of rotation to have a neat identical look is 120. (xxi) A ——— consists of one face only. (xxii) A ——— is a closed form consisting of 24 like faces. (xxiii) A ——— embraces maximum number of faces in hexagonal system. (xxiv) ——— of symmetry denotes as if reflection of one half through a point to obtain the remaining half. (xxv) For a ——— axis, minimum amount of rotation to have neat identical position is 60.

19. Below are given several form names. Mention whether they are closed and open and write down the number of faces :

Rhombodecahedron ; Rhombohedron ; Basal Pinacoid ; Macrodome ; Ditetragonal Prism.

20. (i) What are the essential characters of a crystal. (ii) What do you understand by single and aggregate crystals. (iii) Define open and close form. (iv) Define a plane of symmetry and axis of symmetry.

21. (a) A columnar crystal broken on either side, shows six vertical faces, each side being of equal length (20 cms) in cross-section, while the interfacial angles between the adjacent faces are 40° (two such angles) and 70° (four such angles). Mention the crystal system

with reasons, given that all the crystallographic axes, excepting the vertical lie on a horizontal plane.

(b) On the above crystal, given that four of the said six faces, intersect two horizontal axes at unity find out a : b.

(c) Find out parameter from the given face-indices :

110 ; 203 ; 421 and 132.

(d) From (c) above, given a : b : c=0·5 : 1 : 1·5 and b=12 cms., find out the actual length of intercept with the crystallographic axes for the said faces.

(e) A crystal shows interfacial angle of 60° between any two adjacent vertical crystal faces, and has its vertical axis unequal in length to the others. Mention its crystal system with reasons.

(f) Find out the total no of crystal faces (give indices) under the given form and under the given conditions : (i) [100]—crystallographic axes equal in length and each is A . (ii) [100]—vertical axis is A but not interchangeable with the horizontals. (iii) [111]—all axial planes are planes of symmetry. (iv) [110]—vertical axis is A and interchangeable with other axes.

(g) Find out, from consideration of symbol or, otherwise, whether faces 600—201—302—203—102 lie on 401—001 zone or not.

22. (a) A crystal face intersects the crystallographic axes a, b, and c each at 5 cm. distance and at their positive sides. Find out the parameter and hence face index, given

(i) a : c=0·5 : 1 : 1·5

b=10 cm.

(b) On a crystal, the following interfacial angles were measured between the six faces, all lying in the same zone :

$f_1 \wedge f_2=30°$ $f_3 \wedge f_4=75°$ $f_5 \wedge f_6=75°$

$f_2 \wedge f_3=75°$ $f_4 \wedge f_5=30°$ $f_6 \wedge f_1=75°$

Mention with reasons the number of forms to which these faces belong, with the respective faces grouped under each form.

(c) In (b) above, given that the crystallographic axes are at right angles, mention the probable the crystal system with reason.

33. Write notes on :

(i) Birefringence (ii) Uniaxial Mineral (iii) Double refraction (iv) Twinning (v) Extinction angle (vi) Pleochroism (vii) Isotropic mineral (viii) Nicol Prism (ix) Becke line (x) Quartz wedge.

34. Give the symmetry elements of the normal class of Orthorhombic system. Name one mineral of this system. Draw a sketch stereogram to illustrate your answer.

35. To which crystal system does each of the following cyrstals belong ?

a. A crystal _ one axis of symmetry along which three planes of symmetry intersect.

b. A crystal having three planes of symmetry and three axis of symmetry.

[illegible] having one axis of hexagonal symmetry. Depict the above characters by sketch stereographic projections.

36. What are the possible elements of symmetry in crystals? Write down in a tabular form the symmetry elements or normal classes of the different crystals systems.

37. Classify the crystals into systems. Enumerate the nature and arrangement of crystals axes and characteristic symmetry elements of the different crystal systems State the crystal systems of the following minerals: Magnetite, Gypsum, Sulphur, Iceland spar.

38. To which crystal systems do the following crystals belong:

(a) A crystal having only one plane and one two fold axis, and the centre of symmetry

(b) A crystal having a centre of symmetry.

(c) A crstal having four-fold axes of symmetry.

(d) A crystal having four planes of symmetry meeting along one axis of symmetry

39 Write notes on

Miller indices, Twining in crystals, Plane of symmetry, Dodecahedron, Centre of symmetry, Symmetry, Crystal axis, Pedion, a crystal class, amorphous matter, plane of twinning, Stereographic projection, Interfacial angle, Contact Goniometer, Indices in Crystallography

40. Draw a sketch of each of the following forms and name one mineral under each

(i) Pyramid, (ii) Prism, (iii) Rhombohedron, (iv) Tetrahedron, (v) Analyser of a microscope, (vi) Cross-line, (vii) Pinacoid, (viii) Constancy of interfacial angles of crystals

41. Present in a tabular from the symmetry elements of Normal classes of various crystal systems, giving examples of at least one mineral crystalling in each of these classes

42 Describe the normal class of Tetragonal system under the following points:

(i) Crystallographic axes, (ii) Symmetry elements, (iii) Name of general form.

43. What is meant by symmetry of crystals? What are elements of symmetry? State the symmetry elements of the normal class of tetragonal system. Draw a neat sketch of a simple tetragonal crystal indicating its crystallographic axes.

44. Describe the symmetry elements of Normal class of Isometric System, with a note on the nature of the crystallographic axes, Name three minerals crystallising under this system.

45. Describe the number of faces, with face symbols and form name under (101) in normal class of isometric, tetragonal, Orthorhombic and monoclinic systems.

46. Write short notes on :
(i) Miller indices, (ii) Closed
(iv) Parameter, (v) Cube, (vi) Pris
graphic axes, (ix) Interfacial ang
hedron ; Zone ; Pyramid ; Twinnin

47. (a) Find out the paramete
321, 102, 211, 210, 001.
(b) Find out the respectiv
being :

(i) 2a ; 1b : $\frac{1}{2}$c ; (ii) $\frac{1}{2}$a : ∝b : $\frac{1}{2}$c.

(c) On a stereogram represent the following symmetry elements and name the corresponding class any system :
(1) $3A_2$; $4A_3$; 6P. (2) $1A_4$; $4A_2$. (3) $3A_2$.

(d) From the given indices of the following faces, find out the parameter :
301, 132, 213.

(e) Given a : b : c : : 8 : 1 : 1·2 and b = 10 Cms.,
(i) Find out the actual length of intercept of faces 234, 412 and 123 with crystallographic axes ;
(ii) Find out indices of faces that intersects axes 'a' 'b' & 'c' at distances, (α) 2 cms, 3 cms and 3 cms & (β) 4 cms, 4 cms & 4 cms respectively.

(f) Find out the zone-axis of faces 011-023-052-011 and state with reasons, whether the following faces lie in the said zone or not :

203 ; 021 ; 111.

48. Distinguish between :
Holohedral and hemihedral form ; Axes of symmetry and crystollographic axes ; Trapezohedron and Trisoctahedron ; Cube and Rhombohedron ; Hemimorphic crystal and Hemihedral form ; Closed form and open form, interfacial angle and axial angle, Crystal and Crystalline, Simple form and Combination forms, axial plane and plane of symmetry, Tetrahedron and octahedron

49. (a) Find out number of faces under
(i) from (100), given the axes are all equal and interchangeable and are axes of binary symmetry.
(ii) form (110), given each of the three axial planes is a plane of symmetry.
(iii) form (110), given the vertical axis is axis of tetragonal symmetry and not interchangeable with the horizontal axes.

(b) Name the crystal system, given the crystal class to be normal and having
(i) One axis of six fold symmetry. What are the number of planes of symmetry ?

(ii) each of the three crystallographic axes of binary symmetry. What are the axial angles?

(iii) three axes of four fold symmetry. How are crystallographic axes named?

50. (i) What are the essential characters of a crystal?

(ii) What do you understand by single and aggregate crystals?

(iii) Define open and close form.

(iv) Define a plane of symmetry and axis of symmetry.

51. Fill up the blanks:

(a) Pinacoid consists of —— faces.

(b) Crystals under Normal class of —— system have 3 planes of symmetry.

(c) 201 is a face that is parallel to —— axis.

(d) —— is a form consisting of twelve faces.

(e) —— is an example of a closed form consisting of six faces.

(f) —— of symmetry divides a crystal into two similar halves, one half being mirror image of the other.

(g) —— System shows maximum order of symmetry.

(h) A —— is an open form consisting of two parallel faces.

(i) A —— is a closed form consisting of twelve like faces.

(j) A —— embraces maximum number of faces under tetragonal system.

(k) 'b' axis is called —— axis in orthorhombic system.

(l) —— of symmetry divides an ideally developed crystal into two equal and equally placed halves.

(m) For a —— axis, minimum amount of rotation to have a neat identical look is 120.

(n) A —— consists of one face only.

(o) A —— is a closed form consisting of 24 like faces.

(p) A —— embraces maximum number of faces in hexagonal system.

(q) —— of symmetry denotes as if reflection of one half through a point to obtain the remaining half.

(r) For a —— axis, minimum amount of rotation to have neat identical position is 60.

(s) 'a' axis is also called —— 'axis' is monoclinic system.

(t) The common form of garnet is ——.

(u) From the point of view of atomic structure of amphibole is a ——.

52. (a) From the given parameter find out corresponding face indices

(i) $1a : \frac{1}{2}b : \frac{1}{3}c$	(iv) $1a : 2b : \frac{1}{2}c$
(ii) $\frac{1}{2}a : \infty b : \frac{2}{3}c$	(v) $\frac{1}{2}a : \infty b : \frac{1}{3}c$
(iii) $\frac{1}{3}a : \frac{1}{3}b : \frac{2}{3}c$	(vi) $\frac{1}{3}a : \frac{1}{2}b : 1c$

(b) A crystal face intersects the crystallographic axes a, b, and c each at 5 cm. distance and at their positive sides. Find out the parameter and hence face index given

(i) a : c = 0·5 : 1 : 1·5.

(ii) b = 10 cm.

(c) On a crystal, the following interfacial angles were measured between the six faces, all lying in the same zone :

$f_1 \wedge f_2 = 30°$	$f_3 \wedge f_4 = 75°$	$f_5 \wedge f_6 = 75°$
$f_2 \wedge f_3 = 75°$	$f_4 \wedge f_5 = 30°$	$f_6 \wedge f_1 = 75°$

Mention with reasons, the number of forms to which these faces belong, with the respective faces grouped under each form.

(d) In (c) above, given that the crystallographic axes are at right angles, mention the probable the crystal system with reason.

(e) Find out parameter from the given indices :

(i) 214, (ii) 203, (iii) 321.

READING REFERENCES

Jensen, E. David, Getting Acquainted with Minerals (Mc Graw-Hill Book Company, Inc.).

Dapples, C. Edward, Basic Geology for Science and Engineering (John Wiley & Sons, Inc.).

Muthayya, V. D., Text Book of Geology for Engineers (Oxford & IBH Publishing Co.).

Bateman, A. M., Economic Mineral Deposits, (John Wiley & Sons.).

Brown, J. C. and Dey, A. K, India's Mineral Wealth (Oxford University Press).

Lindgren, W., Mineral Deposits (Mc Graw-Hill).

Dana, E. S. & Ford, W. E., A Text Book of Mineralogy (John Wiley & Sons.).

Read, H. H., Rutley's Elements of Mineralogy (Thomas Murley).

Winchell, A. N., Elements of Optical Mineralogy, Part I & II. (John Wiley & Sons.).

Mukherjee, P K., Text Book of Geology (The World Press Private Ltd. Calcutta).

Dutta, A. K, Introduction to Physical Geology (H. R. Dutta, Ranchi, Bihar.).

Ray, S., A Text Book of Geology (Orient Longman Limited, Hyderabad, Bangalore.).

Krishnaswamy, S, India's Mineral Resources (Oxford & IBH Publishing Co. Calcutta).

Betekhtin, A., A Course of Mineralogy (Moscow Peace Publishers).

Flint, E., Essentials of Crystallography (MIR Publishers, Miscow.).

Kirkalday, J. F., General Principles of Geology (Hutchinson & Co. Ltd. London W_1).

Deer, Howice & Zussman, Rock Forming Minerals (Longmans) Vol. I, II, III).

M. J. Buerger, Elementary Crystallography (John Wiley & Sons, Newyork.).

A. P. Cracknell, Crystals and their Structures (Pergamon Press, London).

Egon Larsen, Atoms & Atomic Energy (Weidenfield & Nicolson Pvt. Ltd., London).

C. S. Hurlbert, Jr., Dana's Manual of Mineralogy (John Wiley & Sons, Inc.).

E. W. Heinrich., Mineralogy and Geology of Radioactive Raw Materials (Mc Graw-Hill Book Company, Inc.).

Palache, Berman, Frondel, Dana's System of Mineralogy, Vol I & II (John Wiley & Sons, Inc.).

Ivan Kostov, Mineralogy (Oliver & Boyd).
Ford, A Text Book of Mineralogy (John Wiley & Sons, Inc.).
Hurlbut, Minerals and How to Study them (John Wiley & Sons, Inc.).
Kalervo, Rankama & Sahama, Geochemistry (The University of Chicago Press).
G. M. Davies, A Students Introduction to Geology (Thomas Muby & Co.).
Sergevon Bubnoff, Fundamentals of Geology (Oliver & Boyd, London).
Sharma, N. L. & Ram, K.S.V., Introduction to India's Economic Minerals (Dhanbad Publications, Dhanbad).
Dana, E. S. & Ford, W. E., A Text Book of Mineralogy (John Wiley & Sons).
Sen, A. K. & Guha, P. K., A Hand Book of Economic Geology (Modern Book Agency Pvt. Ltd. Calcutta).
Smith, H. G., Minerals and Microscope (Thomas Murby & Co.).
Pirsson, L. V. & Knoff, A., Rocks and Rock Minerals (John Wiley & Sons.).
Berry, L. G and Mason, B., Mineralogy (W. H. Freeman & Co.).
Niggli, Paul, Rocks and Minerals Deposits (W. H. Freeman & Company).
Rastall, R. H., The Geology of Metalliferous Deposits (Cambridge University Press).

INDEX

A

NOTES